THE GREAT ICE AGE

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TO ILLUSTRATE THE IMBRICATION OF THE DRIFT-SERIES. (See p. 730.)

THE

GREAT ICE AGE

4695-3

AND ITS RELATION TO THE ANTIQUITY OF MAN

BY

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THIRD EDITION, LARGELY REWRITTEN

WITH MAPS AND ILLUSTRATIONS

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1894

This work, formerly inscribed to my dear friend and teacher, the late Sir Andrew Crombie Ramsay, LL.D., F.R.S., Director-General of the Geological Surveys of the United Kingdom, I now dedicate affectionately to his Memory.

PREFACE

TO

THE THIRD EDITION.

SINCE the last issue of this book, seventeen years ago, the number of workers in glacial geology has greatly increased. This is true not only of our own but of other countries, so that the student who essays to learn something of the present position of that department of the 'stony science' has to encounter an abundant literature, somewhat widely scattered, and often difficult of access. In a treatise dealing mainly with the historical geology of glacial times, some general account of the evidence must necessarily be given, but I have not attempted to discuss all the interesting questions mooted and canvassed in the bulky literature referred to. To keep my sketch within reasonable limits I have been compelled to follow more or less strictly the lines I laid down for my guidance in the first edition, wherein it is stated that my endeavour has been to give a systematic account of the Glacial Period, with special reference to its climatic conditions. All the more important features of the evidence, however, have been considered; and, as I have referred freely to original sources of information, my book may serve in some sort as a guide to the literature in question.

In 'Prehistoric Europe,' published in 1881, I had an opportunity of discussing the evidence which had accrued since the appearance of the second edition of the present work, and in the revised and extended re-issue now in the hands of the reader, I venture to continue my résumé of the results arrived at by glacialists, and to formulate the con-

clusions to which a study of those results has led me. It is hardly necessary to do more than indicate very generally in what respects the present differs from the preceding edition. I may mention that the chapters dealing with the phenomena of existing glacial action in Alpine and Arctic regions have been carefully touched up, and the glacial geology of Scotland has likewise been thoroughly revised. Several rearrangements of other matter have been made. Thus, the discussion of the cause of glacial climatic conditions is now removed to the end of the volume. Its former position in the earlier part of the book had led some to believe that my explanation of the evidence was necessarily bound up with the late Dr. Croll's astronomical and physical theory. It will now be seen, I hope, that this is not the case. If I have read the geological evidence aright, the views supported by me will stand, even should Dr. Croll's theory eventually fail to find general acceptance.

With the exception of these revised and rearranged portions, the rest of the matter, extending to nearly three-fourths of the volume, is entirely rewritten. The glacial and interglacial deposits of the Continent are now treated more fully than was possible ten or fifteen years ago. To enable me to accomplish this part of my work I have from time to time visited many of the regions described—verifying the results obtained by others, and comparing and correlating the evidence. The field of labour is very wide, however, and no one can be more sensible than myself how inadequate is the sketch I have attempted. Much that has greatly interested me in the works of my fellow-labourers I have reluctantly left unnoticed—considerations of space alone forbidding me to travel beyond the limits of my special inquiry. It is probable, also, that important contributions, quite pertinent to the subject in hand, may have escaped my attention. Indeed, had it not been for the kind assistance of friends and correspondents, not a few of the works I have been able to read might never have come under my notice. Those who know the extent of foreign glacial literature will not, I believe, condemn me severely for any omissions under this head of which I may have been guilty. At the same time it may be as well to add that the works to which reference has

been made bear only a small proportion to those which have passed through my hands without seeming to call for special notice.

May I further remind the geological reader that I do not profess to write the history of the rise and progress of glacial geology, but simply to sketch its present position. Scant notice, therefore, has been taken of many of the views and opinions held by the pioneers in this department of science —views which, we may well believe, they themselves, had they lived into our day, would have been among the first to discard. In dealing with questions still under discussion I have endeavoured to avoid a controversial tone. But this has not always been possible. As a rule, however, I have preferred simply to set forth the evidence as clearly and impartially as I could, and thereafter to point out what seemed the most reasonable interpretation. It would have been impossible, even had it been desirable, to discuss and controvert every opinion with which I chanced to disagree. Occasionally, it is true, I have examined alternative interpretations the plausibility of which has commended them to some experts in glacial geology. But in general I have been less concerned in attempting to undermine and overturn, than in trying to build up; for I agree with the German critic who asks: 'Muss denn immer das Neue auf den Trümmern des Alten sich erheben, kann nicht auch das Neue sich selbständig aufbauen?' As regards the mere description of geological phenomena my own observations have almost invariably served to confirm those of glacialists who have preceded me; nor does our interpretation of the facts often differ. But in discussing the general bearing of local phenomena on the wide question of the succession of events in glacial times, certain conclusions to which I have been led may possibly be considered heterodox. All that need be said here on the subject is that the generalisations referred to have not been arrived at without careful examination of a wide range of evidence. The chief results were worked out some three or four years ago, and my time since then has been largely occupied in further testing and proving them. Although the conclusions reached are necessarily in advance of those set forth in the earlier issues of this work and in 'Prehistoric

Europe,' yet the general position maintained is the same. It has become increasingly evident that during the Glacial Period cold and genial conditions alternated, and that Man then lived in Europe.

Nowhere has glacial geology been more actively prosecuted in recent years than in America. There, as in Europe, a large and increasing literature is being amassed. Although I have steadily endeavoured to keep abreast of this, and am not without some personal acquaintance with the glacial accumulations of Canada and the United States, I thought that a summary of the American evidence by a recognised authority would be more satisfactory than one prepared by myself. I therefore took the liberty of appealing to my friend Professor Chamberlin, whose knowledge of all that pertains to the glacial geology of North America is at once extensive and profound. I did so with some hesitation, for Professor Chamberlin is a very busy man. But he most kindly undertook to furnish me with the interesting and important sketch which forms Chapters XLI. and XLII. of this volume. While I here gratefully acknowledge my indebtedness, I feel sure that my friend's contribution will be welcomed by geologists on this side of the great water. I ought to mention that, owing to his absence with the Peary Relief Expedition in Greenland, Mr. Chamberlin has unfortunately had no opportunity of revising the proofs of his chapters.

I have throughout indicated the sources of my information, but cannot close these remarks without expressly acknowledging the assistance and advice obtained from scientific friends at home and abroad. My old colleagues, Messrs. B. N. Peach and J. Horne, with whom I have enjoyed the privilege of discussing various theoretical questions treated of in these pages, I have to thank for valuable notes and suggestions. In like manner I am indebted to my friend Professor Penck, of Vienna, for numerous communications relating to the glacial phenomena of the Alpine Lands, the Pyrenees, Auvergne, and other regions which he has critically studied. When some years ago I informed him of the conclusions to which my examination of the glacial deposits had led me, it was with no small satisfaction I found that he had arrived at similar results from his

investigations in the Alpine Lands. That two geologists working independently should have come to practically the same conclusion as regards the 'glacial succession' is not without its bearing on the reliability of their interpretation of the evidence.

JAMES GEIKIE.

EDINBURGH: *July* 25, 1894.

FROM PREFACE TO FIRST EDITION.

'IN the following pages I have endeavoured to give a systematic account of the Glacial Period, with special reference to its changes of climate. My intention at first was to restrict myself to a brief description of British glacial and postglacial deposits, for the purpose of pointing out the general succession established, or in process of being established, by geologists in this country; and, thereafter, of drawing some conclusions as to the position in the series of the Palæolithic gravels, &c., of southern England. But I eventually found that, in order to make my argument intelligible to non-specialists, it would be necessary to describe in detail some sufficiently large area, in which glacial deposits might be considered as typically developed. It is for this reason that I have entered so fully into the geological history of glacial and postglacial Scotland. In delineating the post-Tertiary geology of that country I have been enabled to discuss many elementary matters which are, no doubt, sufficiently familiar to my fellow-hammerers, but which a general reader could hardly be expected to know. In short, while treating of the Scottish deposits I have endeavoured to explain the mode of investigating, and the principles of interpreting glacial phenomena. I also thought that by confining detailed sketching to the glacial history of a well-defined region, it would be possible to convey to the reader's mind a more vivid impression of what the Glacial Period really was, than if I ventured to take a wider canvas. But my chief aim throughout has been to indicate the succession of climatic changes that obtained during the Glacial Period—not in Scotland alone, but in every glaciated region which has been carefully studied by geologists. For I have long been of opinion

that until this has been done, until we clearly understand what the succession of changes during the Ice Age was, it is premature to speculate upon the geological age of those deposits which yield the earliest traces of man in Britain. The great difference that obtains between the fauna of undoubted postglacial and recent beds in Scotland, north of England, Wales, and Ireland, on the one hand, and the cave-deposits and Palæolithic gravels of southern England on the other, has long been a puzzle to me, as it has, no doubt, been to other geologists. But it was not until years had been spent in the study of the glacial deposits that what I conceive to be the true explanation of the difficulty dawned upon me.

'Geologists are aware that the postglacial age of the cave-deposits has not infrequently been called in question. Dr. Buckland, Mr. Godwin-Austen, and Professor (afterwards Sir A. C.) Ramsay, have each expressed a belief that some of our cave-deposits may date back to preglacial times; and Mr. Godwin-Austen long ago pointed out that the "sub-aërial beds" of the English Channel districts were the equivalents of the glacial deposits elsewhere; and that the broad alluvia of our more southerly rivers, such as the Severn, the Fal, the Dart, and the Thames, belong to a period prior to the great submergence, during which [as was then generally believed] the high-level marine drifts of Wales were accumulated. In other words, he showed that these river-gravels could not be referred to postglacial times. Within more recent years a modification of Mr. Godwin-Austen's view has been energetically put forward by Mr. W. Boyd Dawkins, who is of opinion that our Palæolithic deposits belong to a time subsequent to the great submergence just referred to. He holds that man and the extinct mammalia lived in the south of England at a period when Scotland, Wales, and the northern districts of England were covered with ice and snow, and when our summers were warm and our winters very severe. Other geologists, however, as Mr. Prestwich, have contended that we have no evidence of warm summers having obtained during Palæolithic times; while yet others have, on the contrary, thought the evidence pointed to a considerably warmer climate than we now enjoy. Sir C. Lyell gives two explanations of the facts, and thinks the commingling of

arctic and southern forms of animal life may point either to a period of strongly-contrasted summers and winters, or to fluctuations of climate; but he is clearly of opinion that all the Palæolithic gravels belong to postglacial times. The Rev. O. Fisher has described a deposit, called by him "trail," which he believes to be the product of land-ice; as it overlies in places Palæolithic deposits, he considers that a glacial period has intervened since the disappearance of Palæolithic man. Mr. J. Croll has referred to the apparently conflicting evidence of the ossiferous deposits, as an indication of former changes of climate, and this is the view which Sir J. Lubbock inclines to support, and which is advocated in these pages. I have, however, ventured an explanation of the peculiar distribution of Palæolithic gravels, differing from any previously advanced. None of these gravels in my opinion is postglacial, but all must be relegated to preglacial and interglacial times. Their absence from the northern districts I account for by showing that they have been swept out of these regions by confluent glaciers, and by the sea during the period of great submergence.

'These views I first broached during the discussion that followed upon the reading of an interesting paper by Mr. W. Boyd Dawkins, at the Edinburgh meeting of the British Association in 1871. But, as the time allowed for discussion at these meetings is necessarily short, I was unable to do justice to my views; believing them, however, to be worth attention, I gave an outline of them in a series of monthly articles in the "Geological Magazine," the first of which appeared in the number for December 1871. These articles I subsequently collected, and re-issued with some additions and rearrangements in the summer of the year following.

'As far as I know, these papers were the first attempt to prove, by correlating glacial deposits, that the palæolithic gravels of southern England could not be of postglacial age, but ought to be referred to interglacial and preglacial times. They also bring forward, for the first time, reason to show that a wide land-surface existed in the British area after the disappearance of the ice-sheets, and before the period of great submergence had commenced.'

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CHAPTER I.

INTRODUCTORY.

THE earlier students of the physical history of our earth considered that a great gap or strongly defined boundary line separated the Present from the Past. Some mighty convulsion of nature was believed to have marked the close of geological time, and to have preceded the advent of man and the introduction of the plants and animals with which he is associated. It was hardly doubted that the present distribution of land and water dated back to an age anterior to the coming of our race, and that when man first entered Britain he had to cross seas that still roll between us and the Continent. In short, it was held that within the human period only a few minor changes had been effected in the physical aspect of our country. It was admitted, indeed, that large areas of forest land had been displenished, that considerable tracts of peat-bog had grown, and that here and there, where the coasts were formed of incoherent materials, the sea had made some inroads; but no one supposed that greater changes than these had come about since the first occupation of Britain.

Subsequent research, however, has overturned many of these opinions, and widened our views as to the magnitude of the physical changes of which man has been a witness. Not only have great oscillations of climate happened within the human period, but the distribution of land and sea also has undergone very considerable modifications. Seas have vanished and returned, wide areas of land have appeared and disappeared—broad and deep valleys have been hollowed out of solid rocks by running water. It is from a

knowledge of these and similar facts that geologists arrive at their estimate of the antiquity of man, and have assured themselves that no mighty convulsion of nature separates the human period from the earlier ages—the deposits which were at one time looked upon as the sure evidence of such a 'break in the succession' being now recognised as only so many links in the chain that binds the present to the past.

The study of these deposits has unfolded a deeply-interesting and almost romantic history. We are introduced to scenes that are in strangest contrast to what now meets the eye in these latitudes: changes of the most stupendous character pass before us; we see our islands and northern Europe at one time enveloped in snow and ice, while from the Alps and other mountain areas enormous glaciers descend to the low grounds. At another time the British Islands are united to the Continent, and the land is occupied by savage men and animals, many of which have long since vanished from the European fauna. In a word, epochs of arctic severity are beheld alternating with epochs of genial climatic conditions—each accompanied by less or greater geographical changes—throughout a protracted cycle of time.

Those who hear of this history for the first time may well be excused if they listen with some incredulity. It seems difficult to understand how the records of such extraordinary events could be preserved; or how, having been preserved, geologists are able to interpret them. Yet there is really no mystery about the matter. Difficulties undoubtedly do arise, and sometimes problems suggest themselves, for which it is hard or even impossible at present to find a solution. Nevertheless the whole matter resolves itself into a question of circumstantial evidence. The facts are patent to every one who will take the trouble to examine them, and the interpretations adduced by geologists can be tested by an appeal to what is actually taking place in the world around us. In the following pages, therefore, I purpose giving an outline sketch of the evidence, and shall mention only such details as may serve to bring the salient points clearly before the mind, while at the same time I endeavour to put the reader, who may chance to be not specially skilled in

geology, into a position to judge for himself as to the reasonableness of the explanations advanced.

The earlier pages will be occupied with an account of the superficial deposits of Scotland and the story they have to tell us. We shall trace out the succession of events that marked the origin of certain loose and incoherent materials which overlie the solid rocks of that country, and are represented by similar accumulations covering vast areas throughout the northern regions of our hemisphere. The consideration of the Scottish deposits will naturally lead us to inquire into the principles upon which these and their equivalents in other lands must be interpreted. I shall then describe in succession the superficial accumulations of other portions of the British Islands, of the European Continent, of Asia, Australasia, and America, for the purpose of ascertaining how far the conclusions arrived at by geologists in different countries harmonise. Having traversed this wide field of inquiry, and become aware that the deposits, which were at one time lumped together and vaguely believed to represent a period of wild cataclysms and convulsions, are really the records of a long series of changes, each of which flowed as it were into the other, I shall finally take up the subject of the antiquity of man.

In considering this difficult but important and interesting question, it will be necessary to refer first to the special evidences which have been adduced by archæologists and geologists, in proof of the great age of our race. Thereafter I shall endeavour to determine what is the exact horizon in geological history of those deposits which contain the very oldest traces of man. My aim, in short, will be to discover, if possible, at what stage during those great climatic and geographical revolutions, which shall have previously engaged our attention, man certainly occupied Western Europe. If we are able to determine this point, we shall have paved the way for eventually arriving at some approximately definite estimate of the antiquity of man in our continent.

CHAPTER II.

GLACIAL DEPOSITS OF SCOTLAND.—THE TILL OR BOULDER-CLAY.

General distribution of Superficial formations—Till or boulder-clay, the oldest member of the series—How this is proved—Character of the till—Stones in the till—Pseudo-bedding in the till—Till developed chiefly upon the low grounds—Its aspect in upland valleys—'Sowbacks' or 'drums' of till—'Crag and tail'—Smoothed and broken rocks below the till—Configuration of mountains and hills—Subjacent and intercalated beds in the till—Résumé.

THROUGHOUT the length and breadth of Scotland occur numerous scattered heaps and ragged sheets of sand, gravel, and coarse débris, and widespread deposits of clay, beneath which in many places, especially in the lowland districts, the solid rocks that form the framework of the country are in great measure concealed. The general character of these superficial heaps and gatherings must be familiar to every one. They appear in the scaurs and bluffs that overhang our streams and rivers, and are often well exposed by the wash of the waves along certain sections of the sea-coast. The traveller by rail can hardly fail to notice them as he is swept along—here capping the rocks with a few feet of sand and gravel, there thickening out so as tc form the whole face of a cutting from top to bottom. In the numerous quarries with which the country is pitted, the rock is commonly crowned with a more or less thick covering of similar materials; while in sinking for coal and ironstone, and in digging foundations for houses and bridges, superficial accumulations of such débris no less frequently occur. Bricks and tiles are manufactured in large quantities from the beds of clay; and the heaps of sand and gravel, occurring as they often do at great distances from the sea, are much in request by builders, farmers, and others.

So widely are the superficial deposits distributed that they may be said to be common to every part of the country, for they are met with from the Shetland Islands to the Cheviots, and from the Outer Hebrides to the east coast. But while they occur over so wide an area they are at the same time very unequally aggregated. In the Highlands and Uplands they appear to be for the most part restricted to valleys—the craggy broken mountains of the north and the rounded swelling hills of the south of Scotland, showing but little trace of them at the higher elevations. Over the intervening Lowlands, however, they spread in broad but somewhat ragged sheets, which are often continuous across wide tracts.

The materials of which these deposits are made up consist principally of stony clay, fine brick-clay, silt, sand, gravel, and a kind of loose débris of earthy clay and stones. At first sight these various beds appear to be confusedly intermingled, and to show little order in the mode of their occurrence. Sometimes stony clay, at other times sand or gravel, overlies the solid rocks. Again, these deposits may be absent, and a fine brick-clay, or a coarse débris of angular stones and large blocks may cumber the ground instead. But this confusion is only apparent—a regular succession does really exist. It frequently happens that in deep artificial excavations or natural exposures, several kinds of loose material occur together. And when this is the case we usually find that the lowest-lying member of the series consists of a more or less tough clay, charged with stones and boulders. Above this stony clay (*till* or *boulder-clay* as it is called) come beds of sand and gravel, or, as the case may be in mountain-valleys, a loose earthy débris of stones and large blocks and boulders. But in maritime districts it often happens that the first deposit resting immediately upon the till is a fine brick-clay. Thus whenever the boulder-clay or till appears in the same vertical exposure with any of the other superficial deposits it invariably lies at the bottom.[1] Hence we conclude that of all these accumulations the till or boulder-clay is the oldest, since it must have been laid down

[1] Exceptionally, as we shall find in the sequel, bedded deposits do in certain places occur underneath boulder-clay.

in its present position before any of the other heaps of material could have gathered over its surface.

It is only now and then, however, that the lowest lying or oldest superficial accumulations are overlaid by later formed deposits. Throughout wide districts stony clay alone occurs, just as in other regions heaps of sand and gravel form the only covering of the solid rocks. Yet we have no difficulty in deciding as to the relative age of the respective beds; for having once satisfied ourselves that till constantly underlies the other deposits, when all occur together in one section, we can have no doubt that the former must be the older accumulation, and that the latter, even when they rest directly upon rock (the stony clay being altogether absent from the district) must have been formed at a later date. A reference to the accompanying diagram (Fig. 1), which represents an ideal cutting or *section*, will help to render these remarks a little clearer. The figure is intended

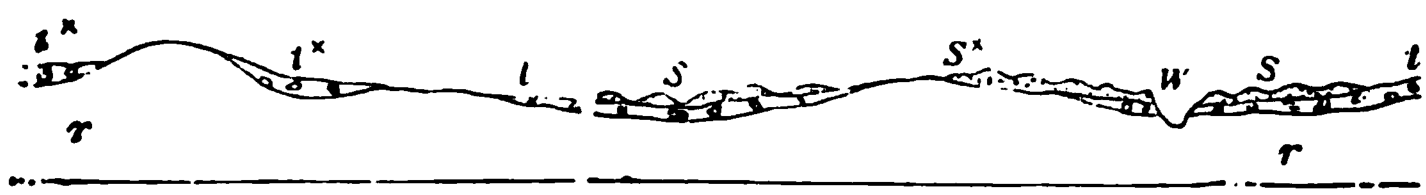


Fig. 1.—Diagrammatic section, showing relative position of till t t^x and overlying sand and gravel series S S^x. W = river valley.

to give a general view of the relation of the underlying till to a very prevalent overlying series of sand and gravel. In this section, t S are the superficial deposits resting upon r r, the solid rocks. It will be observed that the stony clay or till, t, is distinctly covered by the sand and gravel S. At S^x the sand and gravel repose directly upon the rocks r, the till being absent at that point; while at t^x till alone occurs. When the superficial formations are viewed upon the large scale they are invariably found to follow the order indicated.

It has just been mentioned that besides sand and gravel various other kinds of materials sometimes overlie the till. To determine the relative position of these accumulations the same kind of reasoning applies. There are other methods, however, by which this is ascertained, but a consideration of these must be deferred to a subsequent page. At present our attention is confined to the boulder-clay or till. This and the overlying beds are known generally as glacial deposits,

and in the present chapter I shall consider the character and phenomena of the most notable member of the series, namely, the *Till*; for which purpose it will be necessary to enter into some little detail. But these details are absolutely necessary if the reader would understand clearly the nature of the problem which a survey of the phenomena suggests. It would, however, lead me far beyond due limits were I to attempt to give anything like an exhaustive account of the till. All I shall try to do will be to gather together into a short space what appear to be the more salient points in the evidence, from an attentive consideration of which the reader will be able to judge for himself how far the inferences set forth in the sequel are justified.

The deposit known as *till* or *boulder-clay* is usually, especially in the Lowlands, a firm, tough, tenacious, stony clay, which gives every evidence of having been subjected to great pressure. So tough indeed does it often become that engineers would much rather excavate the most obdurate rocks. Hard rocks are more or less easily assailable with gunpowder, and the numerous joints and fissures by which they are traversed enable the workmen to wedge them out often in considerable lumps. But our stony clay has neither crack nor joint[1]—it will not blast, and to pick it to pieces is a very slow and laborious process. Often, however, the accumulation becomes coarser and sandier, and when this is the case water soaks through it. It then loses consistency, and is sometimes ready to 'run' or collapse as soon as an excavation is made. Again, in certain districts it might be described as a coarse agglomeration of subangular and angular stones set in a scanty matrix of coarse earthy grit and sand, as in the lower tracts of many of the islands of the Hebrides. A still more abnormal kind of till is found occasionally in sandstone districts. It consists of an exceedingly rude débris of the underlying sandstone, intermingled with which occur a few stones brought from a distance. The sandstone blocks are of all sizes and shapes, from two or three inches up to fragments five feet and more in diameter. In some places they are heaped confusedly together, with little or no matrix in the

[1] This is the rule: occasionally, however, boulder-clay is traversed by irregular joints, or natural division-planes.

interstices between the blocks. In other places, however, we find the stones set in a more or less meagre matrix of clay and sand. This rude kind of till sometimes attains a thickness of more than twenty feet, as in the moors near Kirk of Shotts, Lanarkshire. It passes gradually into till of the normal type.

Sometimes the stones in the till are so numerous that hardly any matrix of clay is visible. This, however, does not

Fig. 2.—Scratched stone (black shale), from the till. (B. N. Peach.)

often happen. On the other hand, they occasionally appear more sparsely scattered through the clay, which may then be dug for brick-making; but this occurs still less frequently.[1] As a rule, the clay forms the larger percentage of the deposit in a mass of normal till; its stony character being generally

[1] My friend Mr. R. L. Jack informs me that at Port Dundas bricks are made out of a typical stony till, the stones being crunched up by a machine.

most pronounced in hilly districts. But to this there are many exceptions.

The stones vary in size from mere grit and pebbles up to

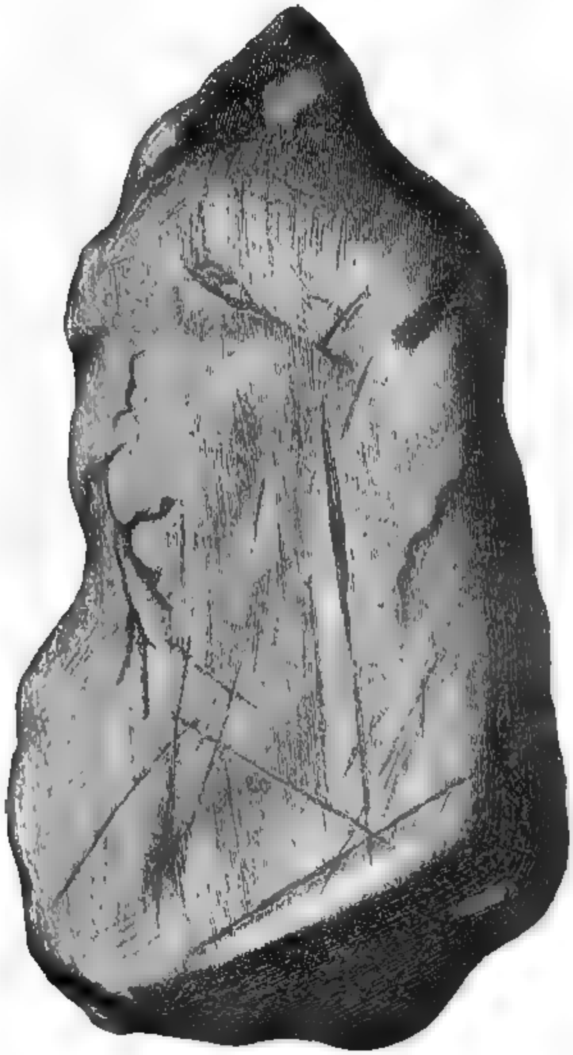


Fig. 3.—Scratched stone (limestone), from the till. (B. N. Peach.)

blocks several feet or even yards in diameter. These last, however, do not occur so abundantly as smaller stones—

indeed, boulders above four feet in diameter are comparatively seldom met with in the till. I think, also, that the bigger boulders are most frequently found in the lower part of the deposit; a position, however, to which they are by no means confined. Perhaps stones varying in size from two or three inches up to six or eight inches in diameter predominate in any mass of ordinary till. Large and small alike are scattered higgledy-piggledy, pell-mell through the clay, so as to give to the whole deposit a highly confused and tumultuous appearance.

There is something very peculiar about the shape of the stones. They are neither round and oval like the pebbles in river-gravel or the shingle of the sea-shore, nor are they sharply angular like newly fallen débris at the base of a cliff, although they more closely resemble the latter than the former. They are indeed angular in shape, but the sharp corners and edges have almost invariably been smoothed away.

Some characteristic forms are shown in the accompanying illustrations (Figs. 2, 3, 4, 5), which have been drawn from actual specimens. Their shape, as will be seen, is by no means their most striking peculiarity. Each is smoothed, polished, and covered with striæ or scratches, some of which are delicate as the lines traced by an etching needle, others deep and harsh as the scores made by the plough upon a rock. And what is also worthy of note, most of the scratches, coarse and fine together, seem to run parallel to the longer axis of the stones, which, however, are scratched in many other directions as well. These appearances are displayed in Figs. 3, 4, and 5. The distinctness of the markings depends very much upon the nature of the stones. Hard, fine-grained rocks, like limestone and clay-ironstone, have often received a high polish or glaze, and retain the finest striæ. Figs. 3, 4, and 5 represent fragments of these. Coarse-grained rocks, like grit and sandstone, are not usually so well polished and scratched; and the same may be said of granitoid igneous and schistose rocks. Fig. 2 shows a fragment of dark carbonaceous shale; it will be noticed that this specimen is not so distinctly oblong as the others, and that the direction of the striæ does not coincide in so marked a manner with the

longer axis of the stone—some of the more strongly pronounced scratches, however, do. It is worth mentioning, also, that there appears to be some curious relation between

Figs. 4 and 5.—Scratched stones from the till. 4. Clay-ironstone. 5. Limestone. (B. N. Peach.)

the coarseness of the striæ and the size of the stones. Thus we usually find that the bigger the stone is the more strongly marked are the striæ. The scratches upon a small fragment are generally very fine, coarse ruts or grooves being absent, while large stones and boulders, besides being well smoothed and closely set with fine striæ, usually exhibit also deep scorings and rough, jagged-edged scratches. It often happens, moreover, that the big blocks are not polished equally all over; sometimes, indeed, they show only one well-polished side, the other faces of the block being rough, and not marked with striæ of any kind. No other appearances connected with the till are more striking than these scratchings and smoothings. They become to the geologist what hieroglyphics are to the Egyptologist—the silent but impressive records of an age long passed away, enabling him to realise the former existence in these islands of a state of things very different indeed from that which now obtains. We must travel to other and distant lands before we can hope to appreciate the full significance of the 'scratches,' or realise all that they suggest.

There is yet another peculiarity of the stones and boulders which is deserving of special note. They show no 'weathered crust': they have evidently never been exposed at the surface of the ground, to the chemical action of superficial water, but are sound and unaltered as if they had been only recently quarried out of the living rock. And the same is the case with the ingredients of the clay in which they are embedded. The mineral constituents of an ordinary alluvial deposit, formed at the surface of the ground, are always more or less highly weathered. They have been derived, in short, from the disintegration of rocks by the chemical action of rain and other superficial agents. But the clay of our till consists of unweathered rock-material, which has been comminuted and pulverised by some other agency. Its constituents, unlike those of a fluviatile silt, have not been oxidised by atmospheric action.

The stones which, as we have seen, occur so abundantly in the till consist of fragments of the various kinds of rock to be met with in Scotland. It must not be supposed, however, that any single section of till will yield specimens of all these

varieties. On the contrary, if we desired to collect from the clay a complete set of the Scottish rocks, we should have to traverse an area as wide as that occupied by those rocks themselves. The till, in short, is quite local in character, for in districts where sandstone occurs most abundantly, the stones in the clay likewise consist almost exclusively of sandstone. And, similarly, in regions where hard volcanic rocks prevail, the overlying till is invariably crowded with fragments of the same. Not only the stones, however, but also the colour and texture of the clay itself are influenced by the character of the rocks in whose neighbourhood the till occurs. Thus, in a district where the rocks consist chiefly of dark shales, clays, and thin sandstones, with occasional seams of coal, the overlying till is usually hard and tough, and its prevailing colour a dark dingy grey or dirty blue; while in a region of red sandstone it is tinted red or brown, and commonly shows a more open or sandier texture.

I have spoken of the till as a tumultuous, amorphous mass; and yet it is not altogether devoid of structure. When we view a good section of it at some little distance, we may occasionally notice a kind of stratification—the stones appearing to show a rude arrangement in roughly parallel lines, which are sometimes horizontal, but more frequently oblique, diagonal, or curved, and even involved. But on a nearer approach, this appearance of stratification often vanishes—we cannot see the structure for the stones. Now and again, however, we may detect similarly arranged layers of less stony clay, alternating with bands more abundantly crowded with stones and boulders. The several layers are not sharply differentiated—there is usually a more or less gradual passage from the one into the other; while not infrequently individual boulders project from an underlying into an overlying layer. Occasionally this rude bedding is marked by differences of colour, and sometimes by distinct lines of stones and boulders. Such appearances are often well seen in the lee of projecting bosses and tors of rock—the stones of the till in such positions tending to lie in sloping layers one over the other, as in Fig. 6. A closer inspection of the till sometimes reveals the presence of a kind of lamination—the clay being arranged in very thin, undulating layers,

which are often puckered and even contorted—reminding one somewhat of the foliated structure of a gnarled gneiss or mica-schist. When the layers are separated their surfaces usually show a polished or glazed appearance—such as may be simulated by dragging the face of one's hammer over a flat surface of the till itself. If the clay of one of the

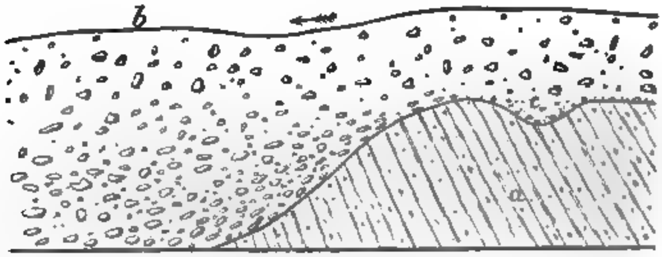


Fig. 6.- Section at east end of Neidpath Tunnel, Peebles. *a*, Silurian rocks; *b*, till, showing arrangement of stones on the lee-side of rock; *c*, gravel in hollow under till. The arrow indicates direction in which the till has travelled.

laminæ be washed and carefully sifted, it will be found to be composed of grains of all shapes, sizes, and weights, down to the finest and most impalpable rock-flour. Another characteristic of till is the not infrequent occurrence of included nests and lenticular layers, and occasionally thick beds of

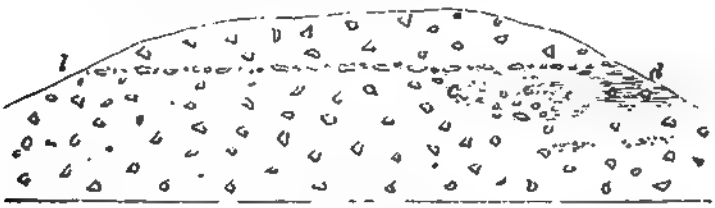


Fig. 7. Section of till: Glen Water, Ayrshire: showing line of stones (*l*), earthy sand with stones (*d*); well rounded gravel and shingle (*c*). Nests of sand are scattered through the amorphous till, shown by stippling below the beds at *d*.

gravel, grit, sand, and brick-clay (see Fig. 7). Sometimes these lie in approximately horizontal or gently inclined positions, but usually they are more or less disturbed, and often curiously curled up and contorted, so as to present the appearance of having been rolled over upon themselves along with the clay in which they are inclosed.

Although the stones and boulders of the till are distributed through the mass without any reference to their relative weight and size, we may yet occasionally observe that within some given area the larger erratics are arranged with the longer axis of each lying in one and the same direction, and the like has been noticed with regard to the smaller rock fragments and grit of the clay.[1]

Lastly I may note as another structural feature of the till the occurrence of what are known as 'striated pavements.' These are horizontal surfaces or levels of till 'where all the prominent boulders and stones have not only their original and independent striæ, but where they have subsequently suffered a new striation which is parallel and persistent across them all.'[2] Such pavements, as one might expect, are more frequently exposed upon a sea-shore than in the interior of the country where horizontal sections of till are seldom seen. Nevertheless, they have been observed now and again, during the operation of clearing the till from the rock-head in quarries.

It is in the lower-lying districts of the country where till appears in greatest force. Wide areas of the central counties are covered with it continuously to a depth varying from two or three feet up to one hundred feet and more. But as we follow it towards the mountain regions it becomes thinner and more interrupted—the naked rock ever and anon peering through, until at last we find only a few shreds and patches lying here and there in sheltered hollows of the hills. Throughout the Highlands it is rarely conspicuous, although now and again tolerably well developed in the bottoms of the broader valleys, and over the more open moorlands. But it is not until we get away from the steep rocky declivities and narrow glens and gorges, and enter upon the broader valleys that open out from the base of the Highlands to the low-lying districts beyond, that we meet with any considerable deposits of stony clay. The higher districts of the Southern Uplands are almost equally free from any covering of till. Occasionally, however, this deposit puts in a bold

[1] H. Miller, 'On Boulder-Glaciation,' *Proc. Royal Phys. Soc.* 1884, p. 157.

[2] A. Geikie, 'Glacial Drift of Scotland,' *Trans. Geol. Soc. Glas.* vol. i. part 2.

appearance in certain hilly regions, as, for instance, in many of the valleys of Peeblesshire, Galloway, and the Border counties, where its aspect is often highly suggestive of its origin. In the localities referred to it frequently forms a more or less broad terrace, sloping gradually with the incli-

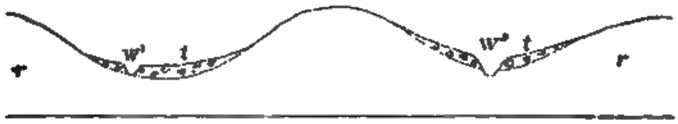


Fig. 8.—Diagrammatic section across two upland valleys: t = till; W^1, W^2 = stream courses; r, solid rock.

nation of the valley in which it occurs. Through this terrace a stream usually cuts a course for itself, and by winding from bank to bank gradually undermines the till, and in some cases has nearly succeeded in clearing it away altogether. A transverse section across two such valleys is

Fig. 9. Greskin Burn, Dumfriesshire: stream cutting through terrace of till. (H. M. Skae.)

given in the diagram annexed (Fig. 8). The cuttings made by the streams are seen at W^1 W^2; t represents the till, and r the underlying rocks. Fig. 9 gives a pictorial representation of the same appearances.

In the Lowlands the till never shows this terrace-like

appearance, but rolls itself out in a series of broad undulations. It is especially worthy of note, too, that the long parallel ridges, or 'sowbacks' and 'drums,' as they are termed, which are the characteristic forms assumed by the till in broad valleys like those of the Tweed and the Nith, invariably coincide in direction with the valleys or straths in which they lie. A section, therefore, drawn across a till-covered area in the Lowlands would give the general aspect represented in the diagram (Fig. 10), where the ridges of stony clay are seen at *t d*.

In the central portion of a broad Lowland valley, where the superficial accumulations are thickest, the drums are invariably composed of boulder-clay alone. Towards the sides of the valley, however, where the till is thinner, the 'drums' occasionally show a core or nucleus of solid rock.

Throughout the midland districts a number of prominent

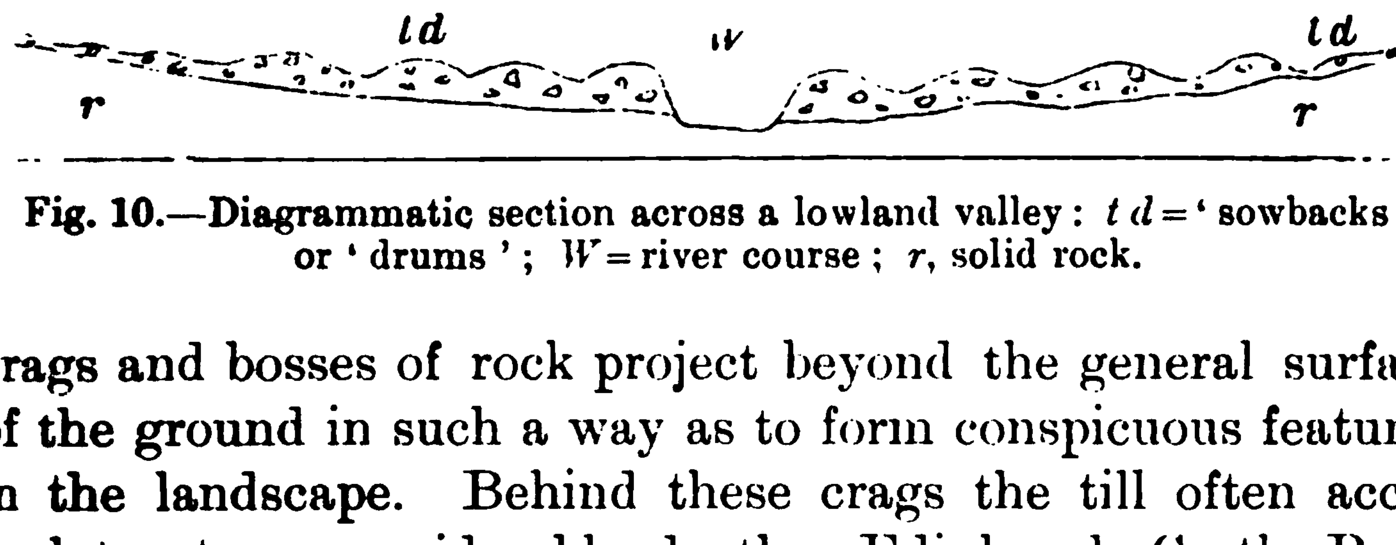


Fig. 10.—Diagrammatic section across a lowland valley: *t d* = 'sowbacks' or 'drums'; *W* = river course; *r*, solid rock.

crags and bosses of rock project beyond the general surface of the ground in such a way as to form conspicuous features in the landscape. Behind these crags the till often accumulates to a considerable depth. Edinburgh Castle Rock affords a good example of this appearance, and Arthur's Seat is another instance on a larger scale. From each of these hills a ridge or tail proceeds with a long gentle slope, and similar appearances characterise the numerous isolated boss-like hills which are scattered up and down the Lowlands. The leading phenomena associated with this 'crag and tail' arrangement are shown in the woodcut (Fig. 11). The 'crag,' *c*, itself is usually composed of some relatively hard volcanic material such as basalt or agglomerate,[1] which intersects softer and more yielding rocks, such as sandstone and shale.

[1] The geological reader will understand that the 'crag' is not necessarily formed of intruded igneous rock. The outcrop of any hard bed, that dips with accompanying softer beds at a low angle, has a tendency to produce 'crag and tail' when the dip happens to coincide with the direction in which the till has travelled.

At the base of the 'crag' there is not infrequently a hollow (seen at *h*) excavated in the solid rocks. Here also the till is either very thin or does not occur at all. On the lee-side of the 'crag,' however, it often attains a great thickness; but a glance at the diagram will show that even were the till completely stripped from the lee-side of the 'crag' a notable 'tail' would still remain, for the rock on the lee-side is considerably higher than the rock at *h*. The phenomena

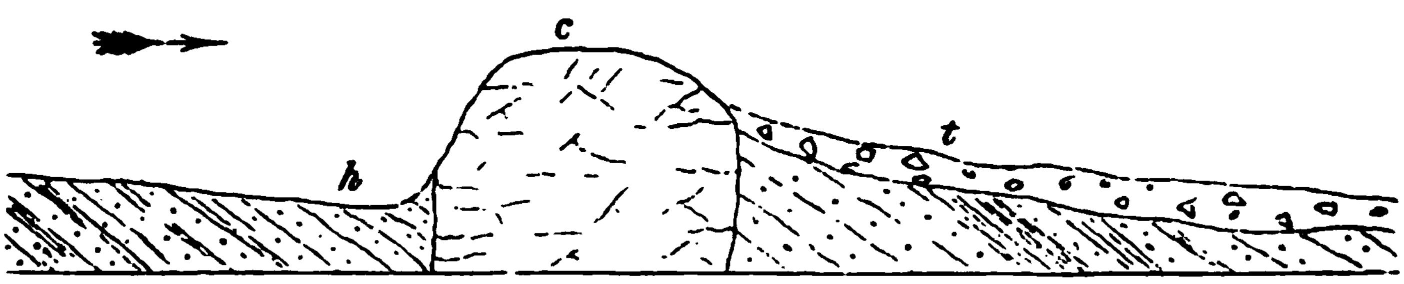


Fig. 11.—'Crag and tail.'

of 'crag and tail' therefore are not entirely dependent upon the presence of the stony clay. They may, and in point of fact do, exist where no till is visible. All that we can affirm in regard to the part played by the latter in the formation of 'crag and tail' is simply this—that in districts where till abounds it is usually heaped up on one particular side of projecting crags or bosses. In Edinburghshire, for example, a greater depth occurs on the east than on the west side of prominent isolated hills. In other districts again it may be on the north, west, or south side where the till has chiefly accumulated.

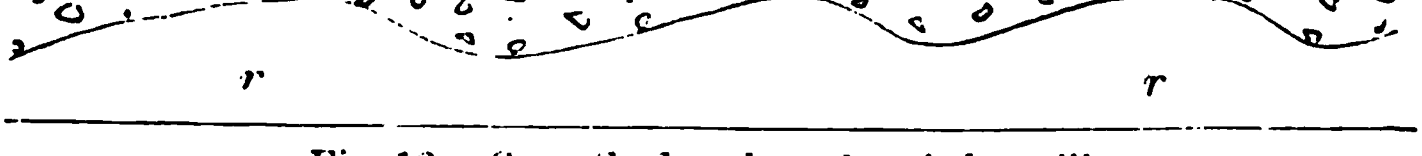


Fig. 12.—Smoothed rock surface below till.

When the till is removed from the underlying rocks the upper surface of these very frequently shows a smoothed (see Fig. 12) and often highly polished appearance, and the whole pavement is marked with those peculiar scratches or striæ that form so characteristic a feature of the stones included in the till. But the extent to which this polishing is carried depends very much upon the nature of the rocks. We have seen that the most perfectly smoothed and striated stones of

the till consist of such close-grained rocks as limestone and clay-ironstone—the striæ upon fragments of sandstone being often faint and ill-defined. The same rule holds good in regard to the rocky pavement upon which the till reposes. Limestone invariably yields a beautifully smoothed and polished surface, and some other rocks, such as serpentine, receive nearly as fine a dressing as a lapidary's wheel could give them. But sandstones and highly-jointed rocks are usually much less finely marked, and often show a broken and shattered surface below till; sometimes, indeed, thick sandstones appear 'broken up' to a depth of many feet below boulder-clay, the coarse angular débris of the sandstone

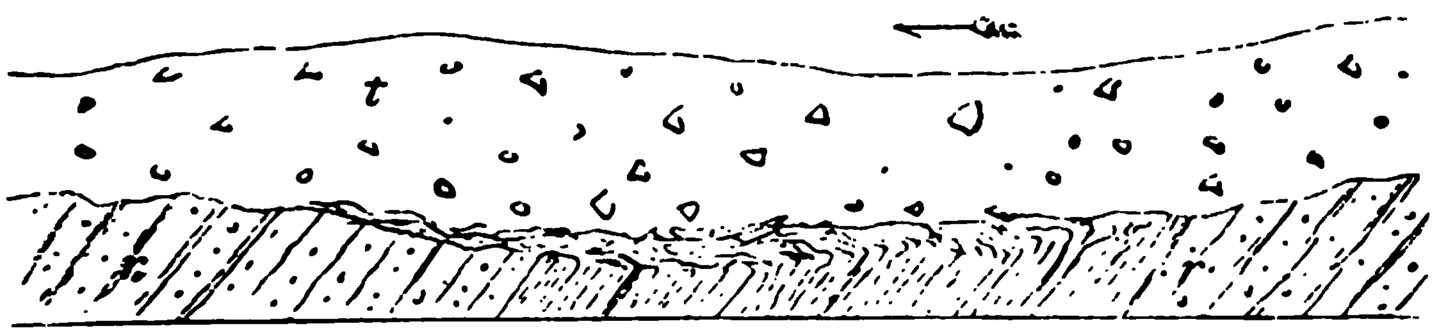


Fig. 13.—Broken rocks below till: near Peebles, River Tweed.

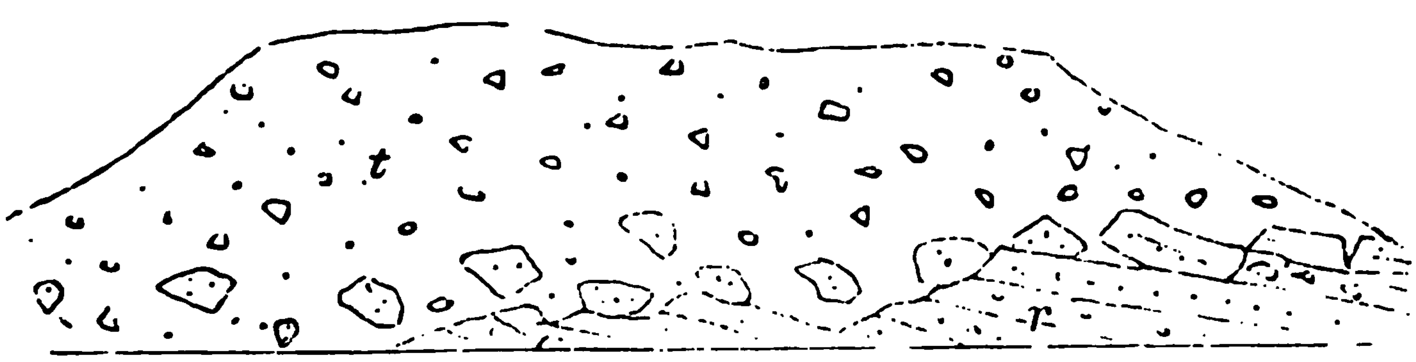


Fig. 14.—Broken sandstone below till: near Union Bridge, River Tweed.

shading gradually into till of the normal type. [See *ante*, p. 7.] (Figs. 13, 14.) Occasionally, also, veins and tongue-like processes of till, coming from an overlying mass of that material, penetrate the subjacent rock by joints and fissures, and have all the appearance of having been injected from above. In districts where the subjacent strata exhibit a confused and smashed appearance, we frequently encounter very large angular erratics inclosed in the till. Some of these are so big that they have occasionally been quarried as if they formed part of the living rock. Near Elgin, for example, we find a mass of Jurassic strata, forty feet in thickness, which rests upon two feet of boulder-clay, and is evidently itself only a huge erratic. A bed of limestone has

been quarried underneath this till, and to get at the rock the overlying till and Jurassic beds have been removed for more than 270 yards in one direction and 120 yards at right angles to that. This is the largest erratic yet observed in Scotland. It has evidently not travelled far.

The direction of the scratches, ruts, and grooves upon the rock-head usually coincides with the trend of the valley in which the till occurs. If, for instance, we took the compass-bearing of a considerable valley running from east to west, we should almost certainly find that the striæ pointed in the same direction. But this rule does not hold true for many of the smaller valleys of the Lowlands. In the Highlands, however, and in the Southern Uplands, the striæ most frequently follow the same direction as the valleys, and thus radiate from the high grounds to nearly every point in the compass. In the intervening Lowlands, their prevailing course is from east and north-east to west and south-west, and from west to east, according as they occur in the western or midland and eastern districts. But a fuller account of these wonderful markings will be better appreciated when we come to discuss the origin of the till or boulder-clay.

There are few who have studied the aspect of Scottish hills and mountains who can have failed to notice that these frequently present a rounded and flowing outline. (See Fig. 15.) Save in some of the wilder regions of the Highlands and Western Islands, there is a general absence of abrupt sharp peaks and ridges. Even the projecting masses of rock which roughen the flanks of the Highland mountains often present a rounded hummocky aspect when viewed from some distance: and a little observation will suffice to show that this peculiar rounded appearance is most pronounced when the slopes of the rugged glens are scanned in a direction coinciding with the inclination of the valleys. Let us take, as examples of what is meant, the well-known Glen Rosie in the island of Arran, or Glen Messan in Argyllshire. As the observer advances up these glens he sees nothing of the rounded outline referred to. The slopes of the mountains bristle with irregular crags and projecting rock-masses, amongst which we look in vain for any such appearance as I have tried to describe. And so the broken and confusedly-

Fig. 15.—Loch Doon (lower reach); illustrating rounded outline of hills and hill slopes. (By B. N. Peach.)

tumbled rocks continue until we reach the corries at the heads of the glens. But no sooner do we turn to retrace our steps than the whole aspect of the rocky slopes appears to change, and even the most rugged projecting bosses show as if they had been rounded off by some force pressing over them in a direction down the glens. And so it is with all the other deep valleys and sea-lochs of the Highlands—the smoothed and rounded rocks look up the glens, the broken and jagged masses face down.

I have now sketched the more salient features presented by the till and the smoothed and rounded rock-surfaces. Before leaving the subject I may here note that although the till is a more or less unstratified mass—having none of the structures which are characteristic of ordinary sedimentary deposits, such as river-alluvia, conglomerate, sandstone, and shale—nevertheless it occasionally contains regular beds of gravel, sand, silt, mud, brick-clay, and peat, and sometimes similar accumulations underlie the till and separate that deposit from the subjacent solid rocks. These stratified intercalations, which are not to be confounded with the lenticular inclosures of gravel and sand referred to on a former page, fall to be described in later chapters. I only mention them now to call attention to the fact that the till overlying them not infrequently differs from the boulder-clay on which they rest in being less hard and tough. It is occasionally sandier and often contains very large blocks and boulders, while at the same time its included stones and boulders are not so invariably well-smoothed and striated—or, to express it otherwise, angular unpolished stones and boulders are usually more common in the upper than in the lower mass of till. Again I may note that the intercalated beds often thin out so as to allow the upper and lower deposits of boulder-clay to come together. But to these and other appearances connected with the intercalated and subjacent beds we shall return by-and-by. For the sake of clearness I shall also defer to another page any account of the fossils which have been obtained in the till and its associated beds.

Not wishing to oppress the reader with too many minutiæ on the very threshold of his investigations, I have omitted

from the preceding brief account of the boulder-clay or till many interesting details, which, however, will come before our attention after we have gained some insight into the mystery of the till itself. But before proceeding to consider some of the theories which have been advanced to explain the origin of this deposit, it may be well to recapitulate the principal facts brought forward in the preceding pages. These may be briefly stated as follows:—

1. The loose accumulations of gravel, sand, clay, and other materials that cover so large a portion of the country, belong, for the most part, to what is termed the *Glacial* formation.

2. This formation consists of various members, of which the most characteristic is a more or less tough stony clay, called *till* or *boulder-clay*.

3. The stones are scattered confusedly through the boulder-clay, and are not arranged with any reference to their relative size and weight, although the largest blocks are not infrequently most numerous in the lower portion of the deposit.

4. They are almost invariably of angular and blunted subangular shapes, and frequently exhibit smoothed, polished, and striated surfaces.

5. They show no 'weathered crusts,' and the matrix of finer-grained materials is similarly unaltered.

6. The stones are generally local in character, that is to say, the till of a sandstone district is charged chiefly with fragments of sandstone; while in a region composed for the most part of rocks of igneous origin boulders of such rocks predominate in the till.

7. A similar connection obtains between the colour and texture of the clay and the prevalent character of the rocks:—in a district where red sandstone abounds the till is red and sandy; in a carboniferous district it is of a dark dingy grey or blue, and usually excessively tough.

8. Till is not wholly devoid of structure. Sometimes a rude stratification appears, marked by lines or layers of boulders, &c.; by alternations of very stony with less stony layers of clay; by a kind of lamination; by the local arrangement of the stones, &c., in the line of their longer

axis; and by the occurrence of striated pavements. The 'stratification' is sometimes horizontal, but more usually diagonal and often curved and even contorted. Nests and irregular patches and lenticular layers and thick beds of water-arranged materials are not infrequently inclosed in till.

9. Till lies thickest in the Lowlands, and thins away as it approaches the mountain-tracts.

10. In upland valleys it has a tendency to assume a terrace-like aspect, while in lowland tracts it shows a broad undulating surface, and is frequently arranged in long round-backed parallel ridges, which trend in the direction of the principal valley of the district.

11. Till is often heaped up on one particular side of prominent hills and rocks, especially in the Lowlands.

12. The pavement of rock below till is frequently smoothed, polished, and striated, more especially if the rock be hard and fine grained; relatively soft rocks, like sandstone and shale, and highly-jointed rocks like greywacké, and many igneous masses, often show a broken surface below till.

13. The direction of the rock-striations coincides generally with the trend of the principal valleys.

14. The hills and mountains commonly exhibit a more or less rounded and flowing outline—the rounded appearance of the crags upon a mountain-slope being most conspicuous to an observer looking down the glens. Viewed in the opposite direction, the rounded and smooth outline disappears.

CHAPTER III.

GLACIERS AND GLACIAL ACTION.

Early theories accounting for origin of the till—Débâcles and waves of translation—Iceberg theory—Glacier theory—Accumulation of snow above snow-line, how relieved—Evaporation, avalanches, and glaciers—Origin of glaciers—Glacier-motion—Viscous theory of Forbes—Observations of Messrs. McConnel and Kidd—Dr. Drygalski on ice of Arctic regions—Glacial action—Subglacial erosion—Formation of moraines.

IN the infancy of the science, or, perhaps, some little time before that, a number of wonderful 'theories of the earth' and 'histories of creation' were ushered into the world, some of which continued to be popular long after their absurdities had been exposed. These curious productions gave full rein to the imagination; they abounded with striking and often terrible pictures, and may still be read with a certain degree of interest. But even after geology had made some progress, and an appeal to nature was recognised as the only safe guide to the interpretation of the facts that began to accumulate, ardent and poetical minds were occasionally too prone to supply the missing links in a chain of evidence by drawing upon the fancy, and when no sufficient 'natural cause' could be discerned, imagination, of course, was bound to supply one. The hypotheses which from time to time have been advanced to account for the phenomena of the till, afford copious illustrations of the truth of these remarks. It would be a great mistake, however, to suppose that an erroneous speculation is always or even often wholly pernicious; for, not infrequently, it does good service by warning the student into closer and more continuous observation, and thus leads to the discovery of new facts which otherwise might have remained for a longer time unsuspected and unknown.

Since the superficial deposits first began to attract the

attention of geologists, we have had an abundant crop of hypotheses, to describe which would be a thankless and useless task. By one of these it was conceived that somehow and somewhere in the far north a series of gigantic waves was mysteriously propagated. These waves were supposed to have precipitated themselves upon the land, and then swept madly on over mountain and valley alike, carrying along with them a mighty burden of rocks and stones and rubbish. Such deluges were styled 'waves of translation,' and the till was believed to represent the materials which they hurried along with them in their wild course across the country. The stones and boulders as they sped down slopes and up acclivities, were smoothed and scratched, and the solid rocks over which they careered received a similar kind of treatment. After the water disappeared the stones were found confusedly huddled together in a paste of clay, but occasional big blocks, often far-travelled, perched in lonely positions on hill-tops, or lay scattered over hill-slopes like flocks of sheep; while mounds of sand and gravel rolled themselves out here and there in the Lowlands. Such in a few words was the hypothesis of great débâcles or waves of translation. It was unfortunate for this view that it violated at the very outset the first principles of the science, by assuming the former existence of a cause which there was little in nature to warrant. Large waves it was known had certainly been raised by sudden movements of the earth's crust, and had several times caused great damage to seaport towns; but spasmodic rushes of the sea across a whole country had fortunately never been experienced within the memory of man. The speculation had only been advanced in a kind of desperation, for geologists were quite at their wits' end to discover any natural cause that would account for the peculiar phenomena of the 'drift,' as the glacial deposits were then termed—they could not see rocks being rounded and scratched nor till being formed anywhere—the causes to which these were due had apparently ceased to operate—and so the perplexed philosophers were in a manner compelled to fall back upon waves of translation. They did not, however, attempt to uphold this speculation very strenuously. It was felt that, even granting the possibility of great

waves of translation having swept across the land, still a number of facts remained which could neither be accounted for nor yet explained away. Such, for example, was the characteristic dressing of the stones. It seemed impossible that these could have been so dressed by running water, no matter how rapidly it flowed. The stones in the bed of a mountain-torrent do not show the scratches which are so characteristic of those in the till. They are smoothed but never glazed or polished, while the mysterious markings that streak the till-stones from end to end are nowhere visible. There was also great difficulty in conceiving how large fragments of rock could be carried from the mountains of the Highlands to the south of Scotland by rushes of water. The water might roll them down from one hill into a valley, but it could hardly push them up another hill, and so repeat the process often in a distance of many miles. Then, again, how did the stones come to be intermingled with fine clay? Surely the current or wave that was sufficiently powerful to force along blocks of stone several feet or even yards in diameter, must have swept the finer matter—sand and clay—to infinitely greater distances. Thus there were a great many loose screws in the hypothesis, and every new fact discovered threatened to make it collapse altogether. Day by day the great waves of translation became more and more apocryphal, until at last they ceased even to be hinted at, and sank quietly to rest for ever.

Next succeeded the iceberg hypothesis, which accounts in a natural way for the transport of large blocks and boulders from one part of the country to another. It supposes the land to have been submerged to a certain depth during the accumulation of the till, at which time icebergs setting sail from the tops of the mountains, which then existed as frozen islets, carried with them loads of earth, sand, and rock, which they scattered over the bed of the sea as they floated on their way to the south. This theory is still upheld by a few geologists as a satisfactory explanation of the origin of the till, but, as I shall endeavour by-and-by to show, it does not discriminate between deposits which have been accumulated at different times and under different conditions. For the present, however, we must leave it; but the phenomena

of icebergs, and what these floating masses are capable of doing, will come before our attention in another place.

The older observers had clearly shown that the agents of geological change as represented in this country failed to supply an adequate solution to the enigma of the mysterious till, with its polished and scratched stones. But the phenomena of glacier regions threw a new light on the subject. Geologists, following the lead of Agassiz, gradually became convinced that in some way or other glacier-ice had to do with the origin of the till; and this conviction deepened as the effects of glacial action became better known. I do not suppose that there is any one nowadays who has given this matter sufficient consideration without coming to a firm belief in the glacial origin of boulder-clay. All are agreed that it is a product of ice-action, but how or in what way it owes its origin to that action appears to be still more or less of a mystery to some. I purpose, therefore, to consider the evidence in detail for the purpose of ascertaining whether a definite conclusion can be arrived at. It is quite clear that no theory can be considered satisfactory which does not explain and account for the various appearances detailed in the preceding chapter. No half-explanation will suffice; the key which we obtain must open a way into every obscure hole and corner; each and every fact must have full recognition in the theory which may be ultimately adopted. Our first duty, then, must be to find out whether the process of dressing rock-surfaces and smoothing and polishing rock-fragments is now in operation, and whether at present any deposits like boulder-clay are being formed and accumulated. I have just said that geologists agree in ascribing the origin of these and other phenomena of the till to glacial action. What then, let us inquire, is the nature of that action, and how do the appearances presented by ice-covered regions serve to explain the origin of the boulder-clay or till?

Every one is aware that the watery vapour which the heat of the sun sucks up from lake and stream and sea, by-and-by condenses and returns to earth. At certain elevations it almost invariably comes down in the form of *snow*; at lower levels it falls as *rain*. It is customary to speak of an imaginary line, called the *snow-line*, above which more snow

falls than is melted or evaporated. This line rises to a great elevation in tropical countries; but as we follow it to north and south it begins gradually to descend, until in the icy regions about the poles it drops to the level of the sea.[1] The line, however, is very far from forming an equal curve from the equator to the poles. Many circumstances conspire to render it most irregular and often rapidly undulating. If the winds that blow across a mountainous country convey much moisture, the snow will descend to a lower level than it would were these winds less charged with moisture. Hence it frequently happens that the snow-line actually rises as it recedes from the equator. At Nevados, near Quito, which is under the equator, the snow-line is reached at 15,825 feet, while on Paachata (18° S.) in the Western Cordillera of Bolivia it rises to 20,000 feet. This difference is no doubt due to extensive radiation and the relative dryness of the atmosphere. It is for the same causes that the limit of permanent snow reaches a lower level on the southern than it does on the northern slopes of the Himalaya. The winds that sweep up from India are laden with moisture, while those that blow from the north have been sucked dry by the heated plains of Central Asia. All the moisture precipitated above the ideal line takes the form of snow; but there are limits to its vertical increase—it does not grow in thickness to an indefinite extent. The hill-tops are being constantly relieved of a portion of their wintry mantle by evaporation, and occasionally great shreds of this mantle suddenly drop away, and disappear down the steeper hill-slopes, carrying ruin and desolation with them when they chance to reach cultivated ground. But neither evaporation nor the constant discharge of avalanches suffices to drain the mountains of their vast reservoirs of snow. This is effected by a regular system of ice-rivers or *glaciers*. Enthusiastic physicists have described these wonders of nature in endless volumes, memoirs, papers, and pamphlets, and each observer has vied with his predecessor in attempting some novel or fuller explanation of their phenomena.

[1] This is not exactly true for Arctic regions. Even in the highest north latitudes hitherto reached, it would seem that the short summer is sufficiently warm to melt the snow away from the land immediately bordering on the sea.

One might think it a cold subject enough to discuss, but the records of science tell another tale. Many a warm word, many a hot fight, have these ice-rivers occasioned. Even the briefest account of the various theories which have been advanced from time to time in explanation of the phenomena of glaciers would occupy more space than I can afford. I must therefore content myself by merely recapitulating what appear to be the general results of the controversy.

Pressure, as every schoolboy knows, will convert a handful of new-fallen snow into a hard lump ; and if the pressure be sufficiently severe, the hardened snow will become ice. Over seemingly frail bridges of snow the adventurous mountaineer will traverse yawning clefts and chasms—for the snow, trodden firmly down, becomes stiff and rigid. It is this property of snow which makes a glacier or ice-river possible. When snow has accumulated to a great depth, its own weight squeezes down its lower strata ; and should the pressure of the overlying mass be sufficiently great, the under portions of the snow will eventually be compacted together into true ice. The passage of snow into ice is simultaneously carried on by alternate thawings and freezings. When the sun shines upon the snow, or a warm wind passes over its surface, the upper layer partially melts, and the disengaged water trickles downwards and congeals again round the snow crystals below, so that by-and-by the snow becomes granular. This process being repeated with each year's accumulations, the whole tends to pass into the granular condition, or, as this kind of snow is called, *névé* or *firn*. Thus partly by thawing and freezing, but chiefly by pressure, the whole mass becomes compacted.[1]

One might at first suppose that the hardened snow or ice should now be as immovable as the rock of the mountain upon which it reclined. We know that a bed of tough clay will rest upon a very considerable slope without sliding downward, and even the loose stones and débris which cover so many hill-sides in a highland country find repose upon an

[1] The beds of snow formed during successive winters are of irregular thickness, each being usually marked off by a 'dirt-line' or crust formed of a mixture of dust, small grit, and occasional remains of insects. MM. Pfaff, Klocke, and Koch have shown that the *névé* itself is not an inert body, its component granules moving both horizontally and vertically.

incline of 30°. At Fourneaux the débris shot out from the mouth of the great Cenis tunnel forms a still steeper slope. Mr. Whymper tells us that 'its faces have as nearly as possible an angle of 45°.'[1] But ice, which is a much more rigid body than even the hardest clay, will move upon a slope that is inappreciable by the eye. And thus it happens that wherever snow attains a sufficient thickness to compress itself into ice, this ice, as the overlying mass continues to receive the tribute of each winter, begins to steal down every slope, however gentle the incline may be. Thus it is that in alpine countries the valleys become more or less filled with streams and rivers of ice, which are constantly fed from the snow-fields above. The snow, packed and pressed into ice, gradually moves off the mountains, and the frozen streams thus formed collect at the head of every valley, down which they pour in those great masses which are known as glaciers.

Why, then, does this hard body behave so differently from other solid substances? What property does ice possess which enables it to creep upon slopes adown which only fluids and semi-fluids can move?

James David Forbes, whose works on glacial phenomena rank among the classics of physical science, came to the conclusion that the motion of a glacier was due to the quasi-viscous or plastic nature of the ice, which moved upon a slope much in the same way as a substance of the consistency of treacle or tar, its own weight being sufficient to urge it forward. When the ice was exposed in the glacier to a peculiarly violent strain, its limited plasticity necessitated the formation of an infinity of minute rents, and the internally bruised surfaces were forced to slide over one another, still producing a quasi-fluid character in the motion of the whole. The same eminent physicist further held that reconsolidation of the bruised glacial substance into a coherent whole might be effected by pressure alone acting upon granular snow, or upon ice softened by imminent thaw into a condition more plastic than ice of low temperature.[2]

The physical research of later years has apparently

[1] *Scrambles amongst the Alps*, p. 62.
[2] *Occasional Papers on the Theory of Glaciers*, p. xvi.

established the truth of Forbes' theory. Messrs. McConnel and Kidd have shown [1] that glacier-ice is composed of crystals varying from one-seventh of an inch or less up to an inch or even four inches in thickness. These crystals are the 'glacier-grains' which are so conspicuous in the névé or firn. The 'ice is a sort of conglomerate of these grains, differing, however, from a conglomerate proper in that there is no matrix, the grains fitting each other perfectly. In the winter, at any rate, the ice on the sides of the glacier looks quite homogeneous. But when the piece is broken off and exposed to the sun's rays, the different grains become visible to the naked eye, being separated probably by thin films of water.' Various experiments showed that the ice was plastic both under pressure and under tension, at temperatures far below the freezing-point—the glacier-grains or ice-crystals apparently slipping over each other. Even the crystals themselves exhibited plasticity, due to sliding-planes, the rate of distortion increasing with the temperature. The granular structure of alpine glaciers is equally characteristic of the inland ice of Greenland. Dr. Drygalski tells us that under the summer sun the surface of the ice acquires a coarse granulated aspect, the grains adhering to each other, but so slightly, that a gentle tap causes them to fall asunder. They vary in size, but are never larger than a walnut, and generally smaller. This loose granular structure seems to extend for some depth from the surface; at all events Drygalski could not hack through it to the underlying sound ice. In fact, he only saw sound ice in places where it had been for some time in contact with water. The loose granular ice of the surface is penetrated by air-ducts in extraordinary numbers, which of course add to the porosity of the mass.[2] It is Drygalski's belief that the motion of the inland ice depends chiefly on the water which finds its way down from the surface. There is no movement at temperatures below the melting-point, and this latter temperature is maintained in the lower strata by the descending waters set free in summer. The extreme cold of

[1] *Proc. Roy. Soc.* vol. xliv. p. 331; xlviii. p. 259.

[2] 'Grönlands Gletscher und Inlandeis,' *Zeitschr. d. Ges. für Erdkunde zu Berlin*, 1892.

winter penetrates very slowly into the ice—the temperature of which as a mass oscillates about the melting-point. Thus the motion of the ice depends chiefly upon its lower layers.[1] But the question of glacier-motion is one for the physicist rather than the geologist. For the latter it is enough to be assured that ice under pressure behaves like other solids similarly placed—it flows. As M. Tresca has shown by many varied experiments, all solids can be made to flow like liquids, and ice is no exception. The latter has only to attain a sufficient thickness, and its own weight will suffice to set it in motion. Thus, with its temperature at or near the melting-point, ice a few hundred feet in thickness cannot remain inert, even although it lay upon a horizontal surface. It would in such a case flow outwards in all directions, until the shearing force came to counterbalance the pressure. If it were not for this plasticity, which enables ice to behave like a viscous body, all the waters of the earth, the myriad rivers, and lakes, and seas, would gradually be lifted up by the heat of the sun, and carried on the wings of the wind to the mountains, there to accumulate in vast and constantly growing masses until ocean and all its feeders had been exhausted. But under the influence of gravitation slowly and gradually the solid heaps creep down hill-slope and valley, their progress being accelerated or retarded according to the temperature. It is thus that during day the motion of the ice is less sluggish than at night; and for the same reason a glacier in summer-time moves more quickly on its way than in winter, when its motion is exceedingly slow, sometimes not reaching to half the summer rate.

We have now learned what are the means which Nature adopts to prevent the increase of snow to an indefinite extent upon the mountains. The under portions of the granulated

[1] Drygalski, *op. cit.* Nov. 1893; *Geograph. Journ.* 1894, p. 49. The late Dr. Croll suggested that the motion of glacier-ice was due to liquefaction and re-solidification of the ice-particles—each as it melted tending to move downwards. These changes he supposed were the result of heat passing through the gelid mass. (*Phil. Mag.* March 1869, September 1870; *Climate and Time*, chap. xxx.) Mr. W. Deeley has endeavoured to show that the cause of glacier-motion is gravity, which effects a slow but continuous change of form in an elastic substance, in the interior of which liquefaction and re-solidification are constantly going on. (*Phil. Mag.* February 1888.)

heaps, which have a slow movement of their own, are gradually squeezed by the superincumbent masses into compact ice, and this ice thereupon begins to creep outwards and downwards. At the head of an alpine valley streams of ice collect from the contiguous slopes, and, becoming welded together into one mass, move down the bottom of the valley, forming a glacier or ice river. It depends upon the size of a glacier, and the temperature of the region into which it advances, whether its journey is to be a long or a short one. Often the ice reaches many thousand feet below the limits of permanent snow. But sooner or later its progress is arrested by the increasing temperature, under the influence of which the ice melts away as fast as it comes down.

In its course from the regions of perennial snow down to where it is cut off by the increasing warmth the glacier has many analogies with a stream or river of water. The velocity of a river varies according to the inclination of the valley down which it flows, and this it would seem is equally true of glaciers. When the course of a river is rocky and falls rapidly, the water is broken, and hurries on tumultuously. In like manner, a glacier that makes its way along a rough and craggy valley shows a broken and tumbled surface. There are waterfalls and ice-cataracts. Again it is known that rivers flow more swiftly at the surface and in the middle than they do at the bottom and sides, where the water is retarded by friction: the same is the case with glaciers. The thread of a river's current moves from right to left of a medial line according as the river winds from one side of the valley to the other; the current of a glacier behaves in the same way. Nay, we may carry the parallel yet further, for the twigs and branches and trunks of trees which drop into a river and float upon its bosom are represented in alpine valleys by the blocks and stones and débris that fall upon a glacier from crag and cliff, and are borne upon its surface down the valley. It was this river-like character and the wonderful manner in which a glacier accommodates itself to the form of its valley, that impressed James David Forbes, and led him to conclude that the motion of the ice was due to viscosity. When, owing to the nature of its bed,

a glacier becomes subjected to excessive strain or tension, however, it is always more or less seamed with gaping cracks or clefts which descend to a great depth in the ice. These *crevasses*, as they are called, have undoubtedly been produced by the snapping of the ice, owing to its limited plasticity under tension. The beginning of a crevasse is often notified by a loud report—the rupturing of the ice. At first the crack may be only wide enough to admit the edge of a knife, but it gradually opens, until frequently it yawns into a wide impassable chasm. The origin of these crevasses is due to the unequal or differential motion of the ice—the glacier moving faster at the surface and the centre than it does at the bottom and the sides, and thus bringing tension into play. Many fissures and crevasses also are caused by the inequalities of the bed over which the glacier flows, for the bottom of a valley does not always, or even often, slope at approximately the same angle throughout: some portions incline more rapidly than others. Now the ice after it reaches in its downward progress the edge of one of these steeper inclines naturally tends to move more quickly, and to drag forward the ice behind it. At this point, then, a degree of tension is brought about, to which the ice can only yield by snapping asunder. When, afterwards, the ice arrives at a gentler and more equable slope, its motion is at once checked, the gaping crevasses begin to close up, and by-and-by disappear altogether, until finally, under the influence of regelation, the ice becomes continuous as before. Thus in its course from the snow-fields to its termination the ice is being continually broken by mechanical strain, and just as constantly these breakages are being repaired by regelation.

The rate of flow of a glacier is regulated, as we have seen, partly by temperature and partly by the slope of the ground; but it is influenced also by the volume of the ice. Other things being equal, a massive glacier moves faster than one which is not so thick, and in the case of glaciers of similar size, those which have the steepest course will also have the quickest motion; while in all cases glaciers flow more slowly in winter than in summer. The angle of slope in the valley-glaciers of such a region as the Alps varies from less than

3° up to 30° or more; but with such a slope as 30° the ice is a mere cataract of fragments. An inclination of 8° or 9°, indeed, suffices to produce a jumbled and tumbled surface. In many cases glaciers flow no faster than from three or four inches to eighteen inches a day, while in others the rate exceeds four feet in twenty-four hours. The average annual flow of the glaciers of Switzerland and Norway and the smallest of the Greenlandic glaciers ranges, according to Heim, between 130 ft. and 330 ft.[1] In the island of Jan Mayen the rate of flow seems to vary considerably in the different glaciers. Thus in summer the Weyprecht glacier, in the middle and near its end, advanced at the rate of about ten feet in twenty-four hours; the Kjerulf glacier at seven inches in the same time, while the Swend-Foyn glacier, where the surface sloped at 40° to 45°, moved at the rate of twenty feet.[2] These rates are much exceeded by the great glacier-tongues that are protruded from the inland ice of Greenland—the average movement of which, in summer, is not less that fifty feet in twenty-four hours. Dr. Helland found that the glacier of Jakobshavn in its central part flowed in July at the rate of 63½ feet in twenty-four hours.[3] About 4,000 ft. nearer the side, in March and April, the rate, as measured by R. Hammer, was 33 to 51½ ft. In the glacier of Itivdliarsuk, Drygalski measured the flow at different parts in the month of July, and obtained rates varying from 13 ft. to 52 ft. 6 inches in twenty-four hours.[4] The highest rate ever noted, namely 100 ft. in twenty-four hours, was observed by C. Ryder in the large ice-stream that descends to the Bay of Augpadlartok. In April the rate of flow at the same place was only 34 ft. a day.[5]

Owing to the form of its valley and the varying inclination of its bed, the motion of a glacier is not the same throughout—increasing here, diminishing there. But in cases where the valley-bottom has a more or less regular inclination the motion progressively decreases with the

[1] *Handbuch der Gletscherkunde*, p. 145.
[2] A. B. von Boldva, *Die österreichische Polarstation Jan Mayen*, 1886, Bd. I. Abth. ii.
[3] *Quart. Journ. Geol. Soc.* vol. xxxiii. p. 18.
[4] *Grönlands Gletscher und Inlandeis.*
[5] Rink, *Zeitschr. d. Ges. für Erdkunde zu Berlin*, Bd. xxiii. No. 5; *Scottish Geograph. Mag.* vol. v. p. 18.

attenuation of the ice. The glacier gradually slows towards the end.[1]

Glaciers, like rivers, are of all sizes. Many have a depth of several hundred feet, and some in polar regions are probably 5,000 ft., or even more, in thickness.[2] It may easily be conceived that the pressure of such enormous masses of ice must have a prodigious effect. When a glacier advances beyond its usual limits everything goes down before it: loose soils and débris are pushed forward, and the strongest and thickest trees are overborne just as if they were so many straws. But striking as these examples of the irresistible force of a glacier may be, the destructive and overwhelming power of ice in motion becomes still more noteworthy when the rocks over which a glacier passes are examined. This may be done in summer-time, when the glaciers shrink from the sides of their valleys. Creeping in below the ice, which it is sometimes possible to do for a short distance, we find the rocks finely smoothed and polished, and showing long striæ and ruts, that run parallel to the course followed by the glacier. If we pick out some of the stones that are sure to be scattered about below the ice, we shall find that some are smoothed, polished, and striated in the same manner as the surface of the rock itself. All this is the work of the glacier. The rocky precipices and mountains that hem in a glacier are always splitting up under the influence of frost, and tons of rock and rock-rubbish are continually rolling down and gathering upon the surface of the ice below. Much of this débris falls into crevasses, and must no doubt occasionally reach the bottom of the ice. The stones then get jammed into the frozen mass, and are pressed against the underlying rock-head with all the weight of the superincumbent glacier. Not infrequently, indeed, much of this subglacial débris becomes included in the lower part of the ice, which then assumes the appearance of a

[1] Heim, *Handbuch der Gletscherkunde*, p. 156.

[2] Nansen thinks that the ice-sheet which envelopes Greenland must attain a thickness in the valleys of at least 5,500 to 6,500 ft. (*Petermanns Mitteilungen*: Ergänzungsheft, No. 105, p. 95.) The vast sheet of ice which covers the south polar regions must attain an enormous thickness. Dr. Croll has endeavoured to show that it cannot be less than twelve miles thick in the interior of the Antarctic regions. (*Climate and Time*, p. 375.)

breccia or conglomerate.[1] Graving tools must also be supplied to the glacier by the wrenching of fragments from its own rocky bed. These and the stones received from the crevasses, thus firmly held in the grasp of the ice, become potent agents in grinding, gouging, and scratching the pavement over which they are forced, while the smaller stones and sand and mud that result from the grinding process complete the striation, smoothing, and polishing of the glacier's bed. Could the ice be removed, we should find the whole bottom of the valley smoothed and polished, and streaked with long parallel ruts and striæ. Every high projecting boss would be rounded and dressed on the side that looked up the valley; while the rock on the lee-side, sheltered from the attack of ice-plough, and chisel, and graver, would retain all its roughnesses. Smaller and less abrupt knobs of rock would be rounded and polished all over, and every dimple and hollow would be similarly smoothed and dressed.

The finer-grained materials employed by the ice in polishing its bed, the impalpable mud and silt, are largely carried out from beneath by the stream that issues at the foot of the glacier. In this manner almost all glacial rivers have imparted to them a turbid appearance, the colour of the water depending upon that of the sediment which it holds in suspension. The water may thus be bluish or milky, red, yellow, or dark grey.[2] The stones employed by the glacier

[1] Brückner, 'Die Vergletscherung des Salzachgebietes,' &c., *Geograph. Abhandl. v. A. Penck*, Bd. i. Heft i. This ground-moraine is most readily studied in late winter at the lower end of a glacier. The river escaping from the *Gletscher Thor* (ice-cave) is then at its lowest, and it is possible to enter the cave for some distance. Here what strikes one is the abundance of rounded and polished stones, and the comparative absence of large blocks. Mud, sand, and small rock-fragments are the dominant materials, and are in places frozen into solid masses. They appear also in the clefts and crevices by which the cave is traversed. (Simony, *Vortrag in der Section Breslau d. deutsch. u. oesterr. Alpenvereins*, 1875, p. 513.) H. Credner has described the occurrence under the Pasterzen glacier of ground-moraine which could not be distinguished from the normal boulder-clay of North Germany. (*Zeitschr. d. deutsch. geol. Ges.* Bd. xxxii. p. 572.) Heim likewise recognises the similarity between that boulder-clay and the ground-moraines of Swiss glaciers. (*Handbuch der Gletscherkunde*, p. 351.)

[2] The amount of sediment swept out from a glacier is often very considerable. The daily discharge of water from the Aar glacier (draining an ice-field 23 square miles in extent) in August, has been computed at 440,000,000 gallons, carrying 280 tons of solid matter. According to Helland ('Om Gehalten af Slam i Bræelve,' *Geol. Fōrening. i Stockholm Förhandl.* Bd. ii.)

in grinding and graving its rocky bed are themselves ground and engraved, and numbers of such smoothed, polished, and striated fragments are pushed out at the foot of the glacier. But they here become intermingled with the vast heaps of débris which have been discharged from the mountains and brought down upon the surface of the slowly moving ice.

These heaps are called *superficial moraines* in contradistinction to the *bottom-* or *ground-moraines* which gather underneath the glacier. They are composed for the most part of rough, unpolished, angular fragments of all sizes, from mere sand and grit up to blocks many tons in weight. As might be expected, they show no trace of any arrangement into beds or layers—large and small stones, huge blocks and gravel, grit and boulders, are all confusedly mixed together. The moraines are not scattered irregularly over the whole surface of the ice, save when the glacier is very narrow, but gather chiefly upon the sides, at the base of the mountain-slopes. The glacier in this manner becomes fringed from its origin to its termination with long mounds or banks of débris, which are constantly dropping over the end of the ice, and adding to the immense piles of rubbish

the Justedal glacier (draining an ice-field 820 square miles in extent) discharged in a summer day 2,000,000 kilogrammes (1,968 tons) of sediment. This, however, is much in excess of the average daily discharge throughout the year, the total annual amount being estimated at 180,000,000 kilogrammes (177,156 tons), besides 13,000,000 kilogrammes (12,794 tons) of mineral matter in solution. The whole amount Helland finds would form a mass equal to 69,000 cubic metres (90,252 cubic yards), or a cubic mass measuring 41 metres (134 ft.) on the side. The same observer has computed the amount of water coming from the Vatnajökul (Iceland)—which drains an ice-field ten times larger than that of Justedal—as reaching 1,677 cubic metres (369,107 gallons) per second in a summer day, or 145,000,000 cubic metres (31,914,500,000 gallons) daily, carrying 110,230 tons of sediment. But the summer rate of discharge is probably two or three times greater than the average for the whole year. Taking various considerations into account, Helland estimates the average discharge of water at 634 cubic metres (139,543 gallons) per second, or 20,000,000,000 cubic metres (4,402,000,000,000 gallons) per annum, transporting 14,763,000 tons of sediment. This amount is equivalent to 5,500,000 cubic metres (7,194,000 cubic yards) of rock, measuring 176 metres (568·8 ft.) on the side. The Vatnajökull thus discharges eighty times as much sediment as the Justedal glacier. ('Om Islands Jökler,' *Archiv for Math. og Naturvid.* 1882, p. 213.) Fred. Svenonius has given an interesting account of the small glaciers of Norbotten, Sweden. From him we learn that the Luotoh glacier discharges in a September day 68,210 cubic metres (15,013,021 gallons) of water, containing 7,878 kilogrammes (7 tons 15 cwt. 7 lbs.) of sediment. This is equal to 3·03 cubic metres (about 4 cubic yards) of rock. Thus in the four summer months 1,454 cubic metres (1,902 cubic yards) of rock are denuded from the area covered by the glacier. (*Geol. Föreningens i Stockholm Förhandl.* Bd. vii. p. 33.)

collected there. These latter are the *terminal moraines*, those fringing the sides of the glacier being its *lateral moraines*. By the union of two glaciers their lateral moraines, at the point of junction, conjoin to form the *medial moraine* of the united ice-flows: and the number of such medial moraines necessarily increases with the number of tributary glaciers.

Terminal moraines often attain a great size, forming mounds of débris several hundred feet in height, from which we may gather how excessive must be the waste of the mountains. In all mountainous regions,[1] indeed, the action of frost upon the rocks becomes abundantly evident. Even in our own country the tops and slopes of our higher hills are often buried to a great depth under the débris which alternate freezings and thawings have wrenched from the solid rocks. In higher latitudes, as in the Færöe Islands and Iceland, the exposed rocks of the heights are almost everywhere broken up in this way. Von Baer found the hills on the west coast of Novaia Zemblia literally covered with their own wreck—no rock, however hard or fine-grained, being able to withstand the summer moisture and intense winter frost of that desolate country. A similar account is given by Mr. Lieber of the mountains in Northern Labrador—the grey gneiss of which has everywhere been riven by the frost into piles and sheets of large angular blocks and débris. Mr. Kennan also, in his lively-written 'Tent Life in Siberia,' tells us how, upon crossing the mountains of Kamtschatka, he found the table-land and hill-tops crowded with great square and angular blocks and slabs of rock, which looked for all the world as if they had rained from the skies! They were undoubtedly the ruins of the solid rock which they covered and concealed, and had been detached by frost acting along

[1] In the upper valleys of the Himalaya the waste is something wonderful. See some graphic accounts of this in Mr. Wilson's *Abode of Snow*. Not less striking are the prodigious masses of superficial débris which cover the slopes of the Rocky Mountains in certain latitudes. Dr. Hayden described some of the valleys (Colorado) visited by him as being 'covered thickly with earth, filled with more or less worn rocks of every size, from that of a pea to several feet in diameter. The snow melting upon the crests of the mountains saturates these superficial earths with water, and they slowly move down the gulch much like a glacier. This is another process of grinding the underlying rocks, smoothing and grooving them.' (*Geological and Geographical Survey of Colorado*, 1873, p. 46.)

the natural joints and fissures. In alpine countries this wrecking of the mountains goes on chiefly by day, and in summer-time. During night, and at early morn, dead silence reigns among the snowy peaks: no streams are heard, no water trickles over the surface of the ice; but when the power of the sun begins to be felt, then the noise of water running, leaping, and falling grows upon the ear; soon the

Fig. 16. Alpine Glacier. (H. M. Skae.)

glaciers are washed by numberless little streams; great avalanches, wreathed in snow-smoke, rush downwards with a roar like thunder; masses of rock wedged out by the frost of the previous night are now loosened by the sun, and dash headlong over the precipices, while long trains of débris hurry after them, and are scattered far and wide in wild confusion along the flanks of the glaciers.

CHAPTER IV.

GREENLAND: ITS GLACIAL ASPECT.

Extent of Greenland—Character of coast and interior—The great *mer de glace*, or inland ice—Size of glaciers—Phenomena of arctic glaciers, and origin of icebergs—Submarine moraines—Surface-moraines and ground-moraines—Glacial rivers—Circulation of water underneath the ice—The habitable strip of coast-land—Formation of ice upon the sea—The ice-foot—Waste of cliffs—Transportation of rock-débris by ice-rafts and icebergs—Action of stranded icebergs upon the sea-bottom.

WE have now acquired some knowledge of facts that bear upon the origin of the Scottish till, but we shall gather yet further aid in our attempts to decipher the history of that deposit by taking a peep at some arctic country. For this purpose we cannot do better than select ice-covered Greenland. That desolate region of the far north, despite the bleak and barren aspect of its coasts, and the horrors of the ice-choked seas that must be traversed to reach its more northern shores, has nevertheless been frequently visited by navigators, who have pushed their investigations many hundred miles north of the Danish settlements. The accounts which they give are chiefly taken up with descriptions of the wild ice-bound coast, few attempts having been made to penetrate into the interior. But after the adventurous expedition of Nordenskjöld in 1883, the famous traverse of the Inland Ice by Nansen in 1888, and the more recent intrepid journeys by Lieutenant Peary, that cannot now be said to be altogether a terra incognita.

The western shores of Greenland have been traced northwards from Cape Farewell, in the latitude of the Shetland Islands, to beyond the 83rd parallel. The eastern and north-eastern coasts have not been so continuously followed, but our knowledge of these has been considerably increased during recent years, thanks to the exertions of German, Swedish, and Austrian geographers. Greenland is over-

fourteen hundred miles long by some nine hundred miles wide, but of this great region only a little strip, extending from near Cape Farewell to 73° north lat. along the western shore, is sparsely colonised—all the rest is a bleak wilderness. It has been estimated, indeed, that fully three-fourths of the land are covered with ice.

The coasts are deeply indented with numerous bays and fiords, which, when traced inland, are almost invariably found to terminate against glaciers. Thick ice frequently appears, too, crowning the exposed sea-cliffs, from the edges of which it droops in great tongue-like and stalactitic projections, until its own weight forces it to break away and topple down the precipices into the sea. The whole interior of the country, indeed, would appear to be buried underneath vast depths of snow and ice, which level up the valleys and sweep over the hills. The few daring men who have tried to penetrate inland from the coast, and Nansen, who succeeded in crossing from sea to sea, describe the interior as desolate in the extreme—far as eye can reach nothing save one dead dreary expanse of white. No living creature frequents this wilderness—neither bird, nor beast, nor insect—not even a solitary moss or lichen can be seen. Over everything broods a silence deep as death, broken only when the roaring storm arises to sweep before it the pitiless blinding snow.

But even in the silent and pathless desolations of central Greenland the forces of nature are continuously at work. The vast masses of snow and ice that seem to wrap the hills and valleys as with an everlasting garment, are nevertheless constantly wearing away, and being just as continuously repaired. The peculiar properties of ice that prevent it accumulating upon the land to an indefinite degree, are just as characteristic of the snow-fields of Greenland as of those of alpine countries. Fast as the snows deepen and harden into ice upon the bleak wilds of Greenland, that ice creeps away to the coast, and thus, from the frozen reservoirs of the interior, innumerable glaciers pour themselves down every fiord and opening to the sea. Only a narrow strip of land along the coast-line is left uncovered by the permanent snow-fields and *mer de glace*—all else is snow and ice.

This had been the opinion generally held by geologists and physical geographers for many years before Dr. Nansen made his adventurous journey, and it is needless to say that the results obtained by that intrepid explorer have amply justified it. Taking the observations of other Arctic travellers with his own, he is led to the conclusion that 'the surface of the inland ice forms part of a remarkably regular cylinder, the radius of which nevertheless varies not a little at different latitudes, increasing markedly from the south, and consequently making the arc of the surface flatter and flatter as it advances northwards.' He points out that this remarkable configuration must to a certain extent be independent of the form of the underlying land-surface, which, to judge from the character of the wild and mountainous coast-lands, probably resembles Norway in its general configuration—if, indeed, it be not a group of mountainous islands. The buried interior of Greenland must in fact be a region of high mountains and deep valleys, all of which have totally disappeared under the enveloping *mer de glace.* It is obvious, as Dr. Nansen remarks, that the minor irregularities of the land 'have had no influence whatever upon the form of the upper surface of the ice-sheet.' That form has simply been determined by the force of pressure—the plastic mass attaining its maximum thickness towards the central line of the country, where resistance to the movement due to pressure must necessarily have been greatest. Thus although the larger features of the ice-drowned land may have had some influence in determining the position of the ice-shed, it is not by any means certain that this central line coincides with the dominant ridge or watershed of the land itself. The greatest elevation attained by the expedition was 8,800 ft. How deeply buried the dominating parts of the land-surface may be at that elevation one cannot tell. It is obvious, however, that the *mer de glace* must be very unequal in thickness. According to Dr. Nansen the average elevation of the valleys in the interior cannot much exceed 1,000 or 2,000 ft., so that the ice lying above such depressions must have a thickness of 5,000 or 6,000 ft. It cannot, of course, lie so deeply over the mountain ridges. The eroding power of such a glacier-mass must be enormous,

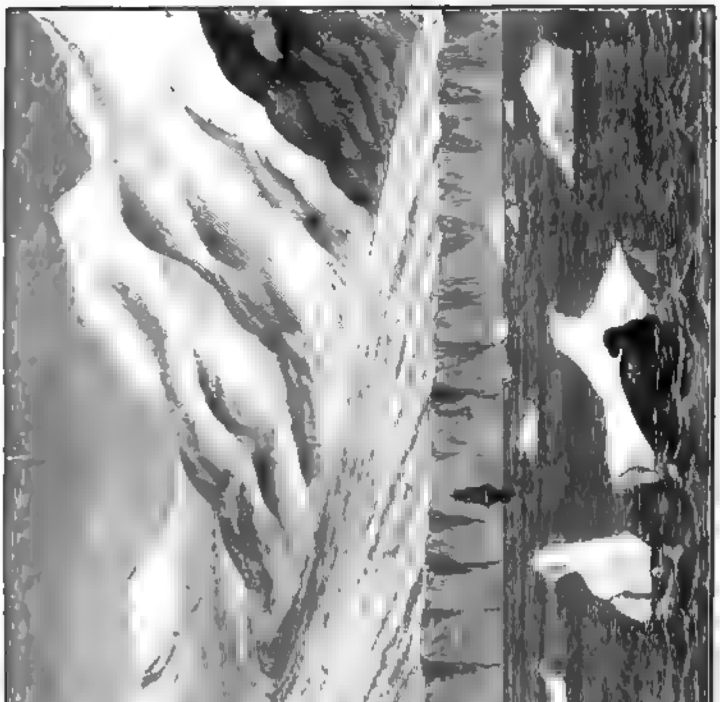


Fig. 17 —Greenlandic Glacier.

and Dr. Nansen does not doubt that the buried valleys of Greenland are being widened and deepened by the grinding of the great ice-streams that are ever advancing towards the sea. (Fig. 17.)

Some of these glaciers attain a vast size. The great Humboldt glacier is said by its discoverer, Dr. Kane, to have a breadth of 60 miles at its termination.[1] Its seaward face rises abruptly from the level of the water to a height of 300 ft., but to what depth it descends is not known. Other glaciers of large size occur frequently along the whole extent of the north-western shores of Greenland. Among these is that of Eisblink, south of Goodhaab, which projects seaward so as to form a promontory some thirteen miles in length. This immense glacier flows from an unknown distance in the interior, and buries its face to a great depth in the sea. A submarine bank of débris forms a kind of semicircle some little way in front of it, and may owe its origin, in part, to the stream that issues from underneath the glacier; but, as we shall see presently, a bank would necessarily gather in the same place, even although no water whatever circulated below the ice.

I have already remarked that the glaciers of Greenland discharge into the sea by fiords and indentations of the coast. If the ice-filled fiords could be cleared out, we should find that these arms of the sea would then occupy deep hollows, continuous with long valleys stretching into the heart of the country. The west coasts of Scotland and Norway afford excellent examples of the kind of scenery that Greenland would present were its fiords and valleys to be freed of ice. In Scotland the fiord-valleys are watered by streams shed from the hills of the interior, but in not a few of the Norwegian valleys the streams that enter the fiords, when followed up, are found to issue from glaciers. In North

[1] According to Nordenskjöld the Humboldt glacier is considerably exceeded by the great glacier or ice-cap of North-East Land (Spitzbergen), which terminates in a precipitous wall along the whole east coast of the island. The map (1867) accompanying his paper (*K. Svenska Vet.-Akad. Handl.* Bd. vi. No. 7), and the map given by Nathorst (*Bihang till K. Svenska Vet.-Akad. Handl.* Bd. ix. No. 2), which is chiefly after Nordenskjöld's chart of 1874, show that North-East Land is almost entirely covered by an ice-sheet. It is the terminal front of this ice-sheet which forms Dickson's Glacier, seventy miles in width.

Greenland, however, the ice generally fills the whole valley, and pushes forward into the sea. Only in a few cases do the glaciers terminate inland and thus give rise to rivers. One may note here, also, that the sea in front of fiord-glaciers is usually more or less discoloured by the fine sediment which is washed out from underneath the ice by subglacial water. Dr. Laube mentions that the water opposite the great glacier of Frederikshaab is discoloured in this manner for a distance of at least three sea miles. During ebb-tide, even at a greater distance from the coast, he could see cloud-like discolourations in the clear water, which he had no doubt were due to the presence of turbid glacial water.[1]

Many arctic glaciers are so thick and massive that they glide boldly on over the bed of the sea, and thus displace the water often for many miles. Instead of the deep fiords being filled with sea-water, as is the case in Scotland and Norway, they are occupied entirely by ice. When the glacier in its downward progress first entered the sea at the head of a fiord, it must have towered for several hundred feet above the level of the water. But as it continued on its course, and crept onward over the deepening bed of the fiord, it gradually buried its lofty face in the waves, until, when it reached the lower end of the fiord and entered the open sea, its front rose only a little height above the reach of the tides. Thus, the sloping platform of ice that faces the sea, however lofty it may be, must bear only a small proportion to the much greater thickness of ice concealed below.

It is well known that ice has a density of about 0·9, so that it readily floats in water. Consequently, when a glacier enters the sea, it is subjected to strain or tension. So long as its bulk, however, much exceeds the depth of the sea, the ice of course rests upon the bed of the fiord or bay. But when the glacier creeps outwards to greater depths, the denser sea-water tends to press it upward. The ice, according to Rink,[2] Helland,[3] and Hammer,[4] has still sufficient cohesion,

[1] *Sitzungsb. der kaiserlichen Akademie von Wissenschaften* (math.-naturwiss. Cl.), Bd. lxviii. p. 45.

[2] *Zeitschr. d. Ges. für Erdkunde zu Berlin*, Bd. xxiii. No. 5; *Himmel und Erde*, 1891.

[3] *Quart. Journ. Geol. Soc.* 1877, p. 142.

[4] *Meddelelser om Grönland*, Bd. iv. p. 19; viii. p. 18.

however, to withstand this pressure for a time, and crawls farther outwards upon the sea-floor. Eventually a stage is reached when it can no longer resist the buoyancy of the sea, and, losing touch of its bed, it begins to flow forward upon a stratum of water. In this way the glacier journeys for some distance beyond the point at which, had it been

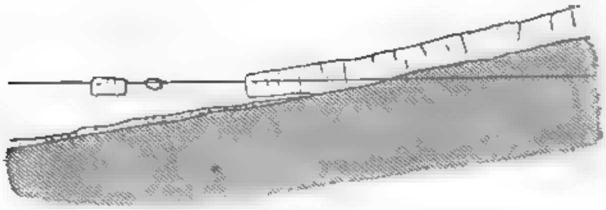


Fig. 18. Glacier calving Iceberg, according to Rink's view.

free, it would have risen and floated. But the great strain to which it is subjected ere long takes effect, and the ice, which has only a limited plasticity under tension, yields by breaking. A larger or smaller segment thus becoming detached from the ice-front surges upwards so as to overtop the latter, and floats away as an iceberg. Such is Rink's view of the matter; but Steenstrup[1] has pointed out, and

Fig. 19.—Glacier calving Iceberg, according to Steenstrup's view: *g*, glacier; *i*, iceberg; *s*, *l*, sea-level; *b*, bottom-moraine; *m*, *t*, morainic matter pushed up in front of glacier.

with him E. von Drygalski[2] agrees, that newly calved icebergs do not overtop the terminal ice-front from which they are shed. They hold, therefore, that a glacier does not advance beyond the point at which the depth of the water is sufficient to float it. It is at this point, they believe, that calving takes place. Hence it is that the icebergs are no

[1] *Op. cit.* Bd. iv. p. 92.
[2] *Zeitschr. d. Ges. für Erdkunde zu Berlin*, Bd. xxvii. (1892).

higher than the ice-front. As arctic glaciers flow much faster than those of alpine lands in temperate latitudes, icebergs are shed or calved in considerable numbers every day.

By the continual advance of a fiord-glacier, quantities of sub-morainic materials tend to accumulate opposite and underneath the ice-front, and these are doubtless partially arranged and assorted by tidal currents and any river of fresh water that may happen to issue from the bottom of the glacier. It is probable that only a very insignificant proportion of the rock-rubbish dragged on underneath the ice-flow is carried away by icebergs. The bottom of an alpine glacier, it is true, is sometimes crowded with ground-moraine, but this, according to the observations of Greely and others, would appear to be exceptional in the case of arctic glaciers.[1] It is evident, therefore, that most of the subglacial detritus brought down from the interior of the country must remain upon the bottom of the fiords. The existence of such frontal or terminal submarine moraines is not merely hypothetical. They are well known to occur—the Tallert Bank in front of the glacier of Eisblink being a very good example.

[1] Greely, who examined many miles of glacier-front in Grinnell Land, remarks that he met with earthy substances included in the ice on two occasions only. The Ella-Valley glacier, with a terminal face nearly two hundred feet high, was stained a chocolate colour, and abundantly charged with small stones and streaks of mud throughout its lower and thicker portion. This glacier, however, occupies a narrow valley hemmed in by lofty heights, which, according to Greely, accounts for the exceptional presence of detritus in the ice. From this it may be inferred that he thought the morainic material was of superficial origin. Such might well be the case, although, judging from the analogy of alpine glaciers, it is not unlikely that some of the débris may have come from the bottom of the ice. However that may be, all arctic explorers are agreed upon the fact that the inland ice of Greenland is wonderfully free from all included material. Nansen remarks that not a single stone or trace of glacial mud was seen by him during his famous traverse. Some geologists have pictured to themselves an ice-sheet crowded with débris—the morainic matter constantly rising up from the bottom as the glacier mass flows on its way. This, as Nansen shows, is a physical impossibility and directly opposed to all observation. But he admits, of course, that now and again great irregularities in the surface over which the inland ice makes its way may sometimes be the means of introducing débris. Thus, should the ice encounter some projecting rock-mass, its lower strata will no doubt be forced to flow round the obstacle, but part will also be pressed over it. The ground-moraine will necessarily travel in the same way—and that portion which is forced over the obstacle will then become embedded in the ice upon the lee-side. See 'Wissenschaftliche Ergebnisse von Dr. F. Nansens Durchquerung von Grönland, 1888,' *Petermanns Mitteilungen*, Ergänzungsheft, Nr. 105, p. 92.

[2] Opposite the whole front of the great glacier of Edge Island (Spitzbergen), there is a similar extensive submarine bank which stretches seawards for fifteen or twenty miles. *Yachting in the Arctic Seas* (Lamont), p. 242.

But before attempting to describe the phenomena connected with floating ice, I have still to glance at some of the appearances exhibited by the ice upon the land.

In general appearance the glaciers of Greenland do not differ, save in size and their comparatively rapid motion, from those of other countries. When the bed of an arctic glacier is rough and irregular, the ice becomes intensely broken and crevassed, just as we saw was the case with the smaller ice-rivers of the Alps. The arctic glaciers are also in summer-time washed by innumerable streamlets and rivers due to the melting of the ice. Baron Nordenskjöld, who made an excursion on the inland ice for a distance of thirty miles from the head of Auleitsivik Fiord (68° north lat.), tells us how his retreat was for a time cut off by a copious, deep, and broad river which could not be crossed without a bridge. But when he followed it in the direction of the current, he found ere long that it rushed with a loud roar down a perpendicular cleft in the ice to the depths below. Again, he and his companion 'saw, at some distance from them, a well-defined pillar of mist, which, when they approached it, appeared to rise from a bottomless abyss, into which a mighty glacier river fell. The vast roaring water-mass had bored for itself a vertical hole, probably all the way down to the rock, situated certainly more than 2,000 ft. beneath, on which the glacier rested.'[1] This, of course, is just the same phenomenon as the well-known *moulin* of Alpine glaciers. In the interior of Greenland, however, Nansen met with no streams of surface-water; indeed, the amount of superficial melting in that region, he observes, was quite insignificant.

Reference has already been made to the fact that morainic matter is not often seen included in the mass of an arctic glacier. According to Dr. Holst, however, the surface of the inland ice as it approaches the coast-lands is covered in places with sheets of angular gravel, grit, and sand of an intraglacial origin. This débris, he says, has been detached by the ice from the prominent rock-ledges overflowed by it on its way to the coast. The fragments thus prised or wrenched off the parent rock-masses are

[1] *Geological Magazine*, vol. ix. p. 360.

enclosed in the upper part of the *mer de glace*, and only come to the surface as the ice begins to melt away on approaching its termination on the coast-lands. The ground-moraine very rarely comes to view, but now and again, owing to the opposition to the ice-flow presented by underlying rock-ledges, some of the morainic matter is forced upwards to the surface, where it becomes commingled with intraglacial angular débris derived by melting from the superior strata of the ice.[1] It would seem, however, that angular débris shed from rocks overlooking the inland ice is of very subordinate importance. Only here and there, indeed, do stones and débris of such an origin appear in any abundance on the surface of arctic glaciers. This is owing to the fact that the whole interior of the country is so effectually concealed beneath its coat of snow and ice that no bare rocky slopes from which fragments might be detached are left exposed to the action of the frost for some distance back from the coast; all the inland valleys appear to be filled up and levelled to the summits of the hills, only the extreme tips of which appear here and there like islands (*Nunatakkr*) above the bleak wastes of the *mer de glace*. Hence there is well-nigh a total absence of those long trains of débris[2] that thunder down the steeps of the Alpine mountains, and gather in heaps along the sides of the glaciers. It is not until the glaciers of Greenland descend to the sea-coast, where the cliffs and mountains that overlook them are more exposed to the action of the weather, that they begin to receive a goodly tribute of blocks and boulders. But the fiord-valleys in which the glaciers lie are in general so broad, that vast expanses of ice show no speck of stone or dust—it is only here and there along their flanks that some bare cliff is able to shower down upon them a

[1] 'Berättelse om en år 1880 i geologiskt syfte företagen resa till Grönland,' *Sveriges Geologiska Undersökning* (Afhandl. o. Upps. Ser. C. No. 81), 1886. Ground-moraine seems to have been seen in great abundance in the glaciers of Jan Mayen by the Austrian Expedition. See A. B. von Boldva, *Aufnahme und Beschreibung von Jan Mayen*, &c. Bd. I. Abth. ii. 1886.

[2] Dr. Rink obtained from the top of a mountain at Upernivik a good view into the interior of Greenland, and saw lines of stones dotting the surface of the ice as far as the eye could reach; from which he inferred that still farther to the east there must be bare cliffs or precipices rising above the *mer de glace*. Dr. Nansen gives graphic descriptions of the Nunatakkr seen by him in his famous traverse of the inland ice.

heap of frost-riven débris. The greatest apparent waste of rocks takes place upon the exposed sea-coasts, where the frost has full freedom to split up the crags and hurl them downwards. But when we think of the immense extent of the glacier system of Greenland, and how in the interior every hill is covered and every valley filled to overflowing with a moving sea of snow and ice, we can hardly overestimate the tremendous wear and tear to which the buried country must be subjected. We have seen what effect the small glaciers of the Alps have in smoöthing and scoring the rocks of Switzerland, and underneath the ice of Greenland similar grinding, and scratching, and polishing must be taking place. Rough crags and sharp projecting bosses of rock will have all their asperities removed; the tops and sides of mountains will be smoothed and dressed, nor can we doubt that valleys will be gradually deepened, and heaps of striated and polished stones will accumulate and be dragged on underneath those mighty ice-rivers which are ever slowly making their way from the interior to the sea. This is not a mere supposition, for ground-moraines are well known to occur in Greenland. They have been described by Holst, Nansen, and others. Dr. Holst, for example, tells us that in the arches and tunnels under the ice-front we may see a bluish clay charged with blunted and scratched boulders;[1] and Nansen mentions the occurrence of similar morainic material at Austmannatjern, where he left the inland ice. He says that the whole upper part of the valley at that place was filled with moraine, composed chiefly of striated and rounded stones, which had obviously travelled underneath the ice as ground-moraine.[2]

All the glaciers of Greenland do not reach the sea. Some even terminate at a distance of many miles from the coast. From the foot of such glaciers streams of water issue and flow all the year round. In some cases these streams unite so as to form considerable rivers, one of which, after a course of forty miles, enters the sea with a mouth nearly three-fourths of a mile in breadth. Dr. Kane,

[1] *Sveriges Geol. Undersök.*, Afhandl. och Upps. Ser. C. No. 81, 1886, p. 50.

[2] *Petermanns Mitteilungen*, Ergänzungsheft, Nr. 105, p. 91.

who discovered and named this river the Mary Minturn River, seems to have been much impressed with the appearance of such a body of fresh water flowing freely at a time when the outside sea was thickly covered with ice. It is highly probable, however, that water circulates to some extent below every glacier, independently of that which rushes down in summer-time through clefts and holes from the surface. The intense cold of an arctic winter penetrates to only a comparatively little distance from the surface of the ground. If it were otherwise—if the winter temperature of North Greenland could penetrate to any depth—it is clear that not a drop of water in its valleys would be permitted to remain in the liquid state, and the short summer would be unable to set free more than that which laves the surface of the inland ice. It is well known, however, that upon digging down through the snow to the underlying soil, the temperature of the latter is found to be considerably higher than that of the external atmosphere. Snow and ice are bad conductors of heat, and thus the warmth imparted to the ground in summer is never entirely dissipated, but imprisoned, as it were, by the investing sheet of snow. In like manner, the rocks that are permanently concealed under the *mer de glace* and the great glaciers must retain pretty nearly the same temperature all the year round. The intense cold of winter cannot pierce entirely through the thick ice; nor, on the other hand, can the higher temperature of the rocks make its escape upwards. Hence any natural springs that may rise below the glaciers will continue to flow on beneath the ice, while the temperature of the rocks themselves—the influence of pressure in lowering the melting-point of ice—and the heat derived from the intense friction of the glacier grinding upon its bed—must tend to liquefy the under portions of the gelid mass, and thus materially add to the volume of water in circulation betwixt the ice and its pavement.

Between the edge of the *mer de glace*, or inland ice, of Greenland and the sea there intervenes a narrow strip of country, from which, in summer-time, the snow almost entirely disappears. In the sheltered nooks of this narrow tract of land the short summer suffices to waken from their

long winter sleep numerous feeble flowerets that gleam and twinkle timidly among thick tufted grasses. Here the purple lichnis and white-starred chickweed, with many other sweet little plants, blossom and bloom under the fleeting sunshine. Dwarf heaths, willows, and alders are also plentiful, and the barren rocks put on a gay livery of orange-coloured lichens. The musk-ox, the reindeer, the arctic fox and hare frequent these solitudes, and numerous flocks of sea-birds enliven the coast; only to disappear, however, as soon as the fading day warns them of the approach of the long night of winter. Of course the Eskimo are entirely confined to this narrow belt of ground adjoining the sea; of the interior of the country they know nothing.

A glance at a map of the western hemisphere will show that Greenland is separated from Labrador, and the bleak islands that flank the northern coasts of America, by a broad belt of water, the wider portions of which are known as Davis Strait and Baffin Bay. Towards the far north this water-belt suddenly contracts to a comparatively narrow strait, the several sections of which are known as Smith Sound, Kennedy Channel, and Robeson Channel—the last-named opening somewhat abruptly in lat. 82° 15′ upon Lincoln Sea. Throughout the greater part of the year all these seas are more or less clogged with ice. In winter Davis Strait and Baffin Bay are nearly all frozen over, but in summer the ice breaks up into a tumbled archipelago of floating islands, through which a few adventurous navigators have made their way with difficulty and danger, and even penetrated as far as the northern coasts of Grinnell Land. Dr. Hayes thought that the accumulation of ice in those seas was favoured by their comparatively sheltered character as compared with the eastern shores of Greenland which are exposed to the full swell of the ocean, so that ice never accumulates there to such an extent as in Baffin Bay and the seas to the north. The high cliffs of the west coast seem in some degree to protect the sea from those fierce storms which in open ocean throw the water into violent commotion and prevent the formation of ice. Dr. Hayes, with a small party, climbed from the shore near Port Foulke and ventured

upwards of sixty miles[1] upon the snow-covered table-land, but was overtaken by a storm of such violence, that it was with great difficulty he succeeded in making good his return. The travellers found, as they descended towards the coast, that they gradually escaped the fury of the wind; and when at last they reached the sea-level, all there was peaceful and quiet: although they could see, by the great clouds of snow-dust which continued to stream out from the crest of the towering cliffs, that the storm still raged with undiminished fury on the bleak table-land above them.

Fig. 20.—Greenlandic Ice-foot. (H. M. Skae.)

The enormous abundance of ice in those confined seas is otherwise accounted for by General Greely. The short summer months, he says, cannot melt the ice formed during the long winter, and as the tides are feeble and the currents weak and uncertain, the ice remains a constant obstruction to navigation.[2]

The ice formed upon the surface of the sea, by direct freezing in one season, rarely attains a greater thickness than six or seven feet; and where the water is liable to more or

[1] Dr. Nansen thinks that the distance travelled could not have been so great. (*The First Crossing of Greenland*, vol. i. p. 473.)
[2] *Three Years of Arctic Service*, vol. ii. p. 44.

less agitation, it is usually much less.[1] There is a limit to the influence of frost upon the sea, just as there is upon the solid ground. Hence the ice-cake comes to assume its maximum thickness soon after the winter sets in; the intense cold of the later winter months adding little, if anything, to its depth.

The sea-ice, where it abuts upon the land, reaches a much greater thickness than that which is formed off shore. Along the coast from near the Arctic Circle northward a narrow shelf or platform, varying from sixty to one hundred and fifty feet or so in breadth, adheres to the rocks, accommodating itself to every sweep and indentation of the coast-line. In the higher latitudes this shelf never entirely disappears, but farther south it breaks up and vanishes towards the end of summer. It owes its origin to the action of the tides. The first frost of the late summer covers the sea with a coat of ice, which becomes adherent to the land, and gradually grows in thickness during the spring tides. In some places, Greely tells us, much ice is pushed upon its surface by the crowding of the main pack against the shore. It may reach a height of thirty feet, and sometimes even more, presenting to the sea a bold wall of ice, against which floes grind and crush, and are pounded into fragments. Its growth only stops with the advent of summer, when it begins to yield to the kindly influence of the sun, and to the action of the numerous streams that issue from the melting glaciers, and lick out for themselves deep hollows in the shelf as they rush to the sea.

During summer, vast piles of rock and rock-rubbish crowd the surface of the ice-foot. These are of course derived from the cliffs, to the base of which the ice-foot clings. To such an extent does this débris accumulate, that

[1] See *Results derived from the Arctic Expedition*, 1875–76 (Captain Sir George Nares). The greatest thickness formed in one season is given by Nares as 79·25 inches. Parry gives the average thickness of the ice that formed in Winter Harbour, Melville Island, as 90 inches (*Journal of a Voyage for the Discovery of a North-West Passage*, &c., 1821, p. 174). Floe-ice, however, often attains a much greater thickness, some floes reaching twenty, thirty, or even fifty feet. But these great thicknesses, according to Greely, are the result of 'underrunning.' When two floes collide the deeper underruns the lighter ice, and huge masses, hundreds of tons in weight, are frequently forced upon the former.

the whole surface of the shelf is sometimes buried beneath it and entirely hidden from view. In the far north, where the ice-foot is perennial, it becomes thickly charged with successive deep layers and irregular masses of detritus—the spoil of the summer thaws; and when, as frequently happens, portions of the ice-belt are forced away from the land by the violent impact of massive floes, the current carries southward the loaded ice, which ere long will drop its burden as it journeys on, and warmer temperatures begin to tell upon it. Along that part of the coast of Greenland where the ice-foot is shed at the end of every summer, the quantities of débris thus borne seaward must be something prodigious.

But the rafts detached from the ice-foot must occasionally float from the coast other records of the land besides fragments of its bleak cliffs. Dr. Kane describes the skeleton of a musk-ox which he saw firmly embedded in the ice of the ice-foot, along with the usual stones and débris. We cannot suppose that this is an isolated and solitary case. On the contrary, when we consider the position of the ice-foot, stretching as it does along the whole coast-line and constantly receiving the waste of the land, it does not appear at all improbable that the remains of the arctic mammalia may not infrequently get frozen into the ice-foot, and eventually be carried out to sea. It is quite true that these animals do not abound throughout the maritime regions of Greenland, yet here and there in favoured spots they collect in considerable herds. Dr. Laube also mentions having seen upon an ice-flow, at a distance of six to ten miles from the coast, many plant-remains, such as saxifrage, vaccinium, willow, &c., which had probably been swept by the wind upon the ice before it was broken up and floated away.

The ice-foot is not the only carrier of stones from Greenland. Glaciers, as we have seen, enter the sea at many places along the arctic coasts—often filling up those long deep sea-valleys or fiords which, in lower latitudes, form commodious natural harbours, and frequently penetrate for many miles into the interior of a country. Of such a character are the sea-lochs and fiords of Scotland and Norway. A glance at a good chart of Greenland will show that

similar inlets of the sea occur very numerously along the west coast of that country as far north as Upernivik. But as we follow the coast-line to still higher latitudes, the sea no longer invades the land in the same way as to the south of Upernivik. The deep fiord-valleys still continue, but they are choked up with glaciers, which have pushed out the sea and occupied its place. As these glaciers slowly creep on to profounder depths, a point is reached at which, as already described, the pressure of the dense sea-water becomes too strong for the tenacity of the glacier to resist; and thereupon the ice ruptures and great masses float away as icebergs. Some of these bergs attain a prodigious size. Dr. Hayes measured one which had stranded off the harbour of Tessuissak to the north of Melville Bay, and estimated it to contain about 27,000,000,000 cubical ft. This berg could not have weighed less than 2,000,000,000 tons; it was aground in water nearly half a mile in depth. What, then must have been the thickness of the glacier from which it had been detached! Captain Ross describes icebergs aground in 150 and even in 250 fathoms of water. One which was aground in 61 fathoms measured, he tells us, 4,169 yards in length by 3,689 yards in breadth and 51 ft. in height.

The icebergs shed from the steeply-sloping and highly-crevassed glaciers that enter the sea through the narrower fiords and inlets are usually of very irregular shape. In the far north, however, where the great inland ice of Greenland descends at a gentler angle to the coast, the icebergs calved from its terminal front are more or less cubical in form, and are known as floe-bergs. They have a remarkably stratified structure—consisting of alternate thin layers of snow and ice with thicker beds of clear ice—a structure which, as Dr. Moss points out,[1] is similar in origin to the stratification seen in alpine glaciers. Greely states that the floe-bergs are usually forty to a hundred feet in height. Some arctic bergs, however, are occasionally two hundred or even three hundred feet high. The largest encountered by Greely rose about ninety feet above the sea, and measured six hundred feet by nine hundred feet across. It was thus nearly a perfect cube.

[1] Nares, *Narrative of a Voyage to the Polar Sea*, vol. ii. p. 59.

It is probable, as I have shown at page 49, that icebergs sometimes carry away with them portions of included bottom-moraine. But the amount of débris thus transported must be relatively small. Here and there, however, the ice will be charged with angular débris, which it has wrenched from the rocky heights traversed by it on its way to the coast. Again, in places where the glaciers are overlooked by rocky precipices, as is frequently the case just before they pour themselves into the sea, their borders become sprinkled with rock-fragments detached by frost from the cliffs above. This would appear to be the case especially with the glaciers that descend to the sea on the east coast of Greenland. According to Scoresby,[1] many icebergs encountered by him in that region contained 'strata of earth and stones, and some were loaded with beds of rock of great thickness, and weighing by calculation from 50,000 to 100,000 tons. One in particular was observed (if it was indeed an iceberg) that was loaded to the height of a ship's mast-head with such piles of rock that only a very few specks of ice were visible.' Nansen also has described an iceberg seen by him off the same coast in 1882, which contained many small stones and large blocks; but this, he tell us, was exceptional—most of the icebergs being free from inclusions of any kind.[2] Similar testimony is borne by Dr. G. C. Laube, who accompanied the German Arctic Expedition of 1869–70. Of the many thousands of icebergs seen by him only a few contained any stones.[3] This is just what we might have expected; for, owing to the great width of most arctic glaciers, only a relatively small part of their surface can be plentifully sprinkled with débris. More especially true is this of those vast lobes or tongues that protrude from the inland ice. Rink, Nordenskjöld, and others are of opinion that stone-laden bergs come chiefly from the small local glaciers which here and there originate in the mountains of the coast-lands. The great Humboldt glacier has a breadth of upwards of sixty miles, and is continually shedding icebergs along its whole vast extent of frontage. But with the

[1] *Journal of a Voyage to the Northern Whale Fishery*, &c. p. 233.
[2] *Nyt Magazin for Naturvidenskaberne*, Bd. xxvii. p. 54.
[3] *Sitzungsberichte der kaiserlichen Akademie der Wissenschaften* (math.-naturwiss. Cl.), Bd. lxviii. p. 27.

exception, perhaps, of those icebergs that break away fro the extreme corners at the north and south, none of t others carry seaward any stones whatever, save such fra ments as may have become jammed and frozen into th bottoms. By far the larger number of the arctic iceber therefore, contain no extraneous matter, and melt away mid ocean without leaving behind them any record of th voyage. Now and then, however, icebergs are heavily lad with débris, and, as bergs float much deeper than detach masses of ice-foot, they come more under the influence oceanic currents, and thus, despite winds and tides, are f quently carried immense distances before they finally m away. Sailors have met with them as far south as t Azores, so that memorials of the arctic lands must widely scattered over the bed of the Atlantic Ocean. It curious to speculàte upon the manner in which the memorials will be distributed across the floor of the s Many deep-sea soundings have made us aware that t ocean is of very irregular depth, and we can easily imagi how, as the melting icebergs drift southwards and drop th burdens as they go, fragments of rock, chipped by the fr or torn by the glacier from the bleak cliffs and mounta of Greenland, will come to rest sometimes upon submari ridges, sometimes in profound abysmal hollows.

Occasionally icebergs run aground, and in this positi are rocked to and fro, and sometimes wheeled about, by t force of the currents. This oscillatory movement is usua accompanied by loud noises, and the sea becomes turl often for more than a mile with the mud which the rocki berg stirs up from the bottom. It frequently happens, t that when a strong swell is running in upon a stranded be the ponderous mass, after for some time swinging fearfu from side to side, heels right over, and splits up into smal fragments, which thereupon float away.

Icebergs do not grate continuously along the bottom the sea; when they once run aground their progress stopped, until by gradual melting, or by breaking up i smaller pieces, they are again floated off and swept on the currents. Now and then, however, a berg propelled the tide may work its way for a short distance over a sh

or up a gently sloping beach; but it is evident that it will do so in a most irregular manner, and will very soon cease to advance. When a berg has stranded, all that currents can do is to drive it forward into any soft mud and sand that may happen to be lying upon the sea-bottom; but the motion of the ice will soon be arrested by the accumulation of débris pushed on in front. A mass of ice 2,000 ft. thick would certainly make havoc of any loose incoherent beds of silt and sand into which it might plough; or, should it run aground upon a reef, it would doubtless pound and crush the hard rocks that formed the pivot upon which it oscillated. But although the rocky coasts of North America have often been examined with a view to discover striated surfaces that could be shown to be the work of icebergs, yet nothing has been observed to lead us to believe that parallel striations and markings, like those produced by glaciers, are ever the result of iceberg action. Floe-ice driven upon a shelving shore sometimes scores and scratches irregularly a rock-surface, by means of the detritus it drags forward. But such 'dressed rocks' have only a specious resemblance to the regularly striated and polished pavements and mammillated surfaces over which a glacier has passed.

In this rapid sketch of certain phenomena of the arctic regions attention has been confined to such facts as have a geological bearing. Nor have all these been exhausted; there still remain some interesting questions to be discussed in connection with the marine life of the arctic regions. But this part of my subject must be deferred to a subsequent page, when I come to consider the history of the later glacial deposits.

CHAPTER V.

ORIGIN OF THE TILL AND ROCK-STRIATIONS AND GROOVINGS OF SCOTLAND.

Stones of the till are glaciated—Till not like terminal moraine-matter—Silt of glacial rivers—Till not an iceberg deposit—Rock-striæ produced by glaciers—Scotland formerly clad with ice—Direction of ice-flow in the Highlands; in the Southern Uplands; in the Lowlands of the great Central Valley—Absence of superficial moraines—Stones in the till derived from the subjacent rocks, not from precipices overhanging the ice—Stones and mud below ice forming a *moraine profonde*, or ground-moraine—Special proofs of the subglacial origin of till—Unequal distribution of this deposit explained.

IN Chapter II. some account was given of the till, the lowest-lying, and therefore the oldest, of the superficial deposits of Scotland. It will be remembered that this deposit was described as a more or less tough tenacious clay, crammed with a pell-mell assemblage of stones—these stones being of all shapes and sizes, and most frequently showing smoothed, polished, or scratched faces. Now, from what we know of glaciers and glacial action, we can have no difficulty in coming to the conclusion that in some way or other ice has been concerned in the production of till. We look in vain for striated stones in the gravel which the surf drives to and fro upon a beach, and we may search the detritus that brooks and rivers push along their beds, but we shall not find any stones at all resembling those of the till. Running water is powerless to produce anything of the kind; it will round and smooth rock-fragments, no matter how hard they be, but it cannot cover them with striations, nor give them the peculiar glaze or polish which the more compact and finer-grained stones of the till so frequently show. The latter undoubtedly owe their shaping and dressing to the action of ice. Stones of precisely the same character, as we have seen, are exposed now and again beneath the over-

hanging sides of a glacier when the sun has caused the ice to shrink back and disclose a portion of its rocky bed, and they may sometimes be picked out of the bottom of its terminal moraines—those heaps of rubbish which a glacier brings down or pushes before it. But we cannot fail to remark that although scratched and polished stones may occasionally be found in the frontal moraines of Alpine glaciers, yet at the same time these moraines do not at all resemble till or boulder-clay. The moraine consists for the most part of a confused heap of rough angular stones and blocks, and loose sand and débris; scratched stones are rare, and indeed a close search will often fail to show one. Clearly, then, till is not of the nature of a terminal moraine. Each boulder-clay stone gives evidence of having been subjected to a grinding process. Either, included in the bottom of a glacier, it has been grated along the rocky surface underneath, or over a pavement of the tough stony clay itself; or, enclosed in the slowly-moving subglacial débris of gravel, sand, and clay, it has in like manner been brought again and again into forcible contact with adjacent blocks and with the rocky floor, as the material gathering below was pressed and squeezed and dragged forward by the ice. Travelling in this manner the stones would naturally arrange themselves in the line of least resistance; hence it is that the most distinct ruts and striæ coincide with the longer axes of the stones. When the rock-fragments, however, were approximately round or oval in shape they could have no tendency to lie in any particular way, and so would come to be scratched equally well in all directions. For obvious reasons, soft rocks, like sandstone, would not receive so good a polish as hard limestone or close-grained shale; nor should we expect to find the stones rounded like gravel or shingle, for they could not move as freely under ice as pebbles do under water. Frequently, however, they would be rolled over and compelled to shift their position; but this process would only result in smoothing off their sharper edges and in marking them with irregular striæ.

We can see also why larger stones should commonly be marked with coarser striæ than are imprinted on the smaller ones; for their own weight in the first place would insure

for them a greater intensity of grinding; and in the next place it is evident that the débris in which such big blocks were embedded under the ice would not yield so readily above them, and consequently they would be subjected to greater pressure upon the rocky bed over which the débris was being dragged. Small stones when they were pressed against the glacier-bed would, on the other hand, rise more easily into the débris above them, and thus escape the deep scoring that marked the larger fragments. If each fragment received its striæ only while held firmly frozen into the bottom of the ice, then there is no reason why the smaller stones should not be covered with as many harsh scorings as the bigger boulders : but the fact that a relation does exist between the coarseness of the striæ and the size of the stone upon which these striæ are engraved, points to the movement under the ice of a considerable mass of subglacial débris.

All the appearances above referred to are actually found, as we have seen, to characterise the stones in the till; and such being the case, we can hardly resist the conclusion that the whole deposit—clay and stones alike—has in some way or other been formed below ice. Now and again, indeed, the ground-moraine of the Alpine glaciers shows all the characters of a true boulder-clay. As a rule, however, it consists rather of an aggregate of angular and subangular rock-fragments and grit. The striated stones we see, but where is the clay? We take our stand at the foot of a glacier and watch the river as it leaps forth from its cave of blue ice. Not a few visitors, I suppose, have been surprised at the turbid appearance of the ice-born river. Why should the melting glacier give rise to such a milky-white, or, as is sometimes the case, yellow-brown stream? If we lift some of the water in a glass and examine it, we shall find that its colour is due to the presence of a very fine impalpable rock-flour. In the more sheltered reaches of a glacial river this mud will occasionally accumulate to some depth. It is an unctuous, sticky deposit, only requiring pressure to knead it into a clay. There can be no doubt whatever that it owes its origin to the grinding power of the glacier. The stones and grit which the ice forces along are crushed and pulverised

against each other and upon the rock below, and it is the finer material (the 'flour of rocks') resulting from this action that renders the glacial rivers turbid and milky. If there were no water to wash out the fine rock-meal formed in this way below the glacier, it is evident that not scratched stones only but clay also would gather underneath the ice, and be pushed out at its termination; and this clay, owing to excessive pressure and to the finely divided nature of its ingredients, would be hard and tough. The till of the Scottish Lowlands, when it has been exposed to the influence of the weather, sooner or later crumbles down, and, when water washes over it, then that which was once a hard tough substance becomes a soft, sticky, unctuous clay, that clings persistently to everything it touches. No one who compares this clay with the silt derived from the glacial waters of the Alps will fail to notice their similarity. Thus, whether we consider the character of the stones in the till, or the nature of the clay, we are almost equally convinced that both have had a glacial origin. It is clear, however, that the conditions for the gathering of a stony clay like till do not obtain to any extent among Alpine glaciers. The upper reaches of the Swiss valleys are, as a rule, too steep, and there is too much water circulating below the ice to allow any considerable thickness of such a deposit as till to accumulate.

Again, till cannot owe its origin to icebergs. Had it been distributed over the sea-bottom it would assuredly show traces of assortment by water. When an iceberg drops its rubbish, it is obvious that the larger blocks will reach the bottom first, then the smaller stones, and lastly the finer ingredients. There is no such assortment visible, however, in normal till; but large and small stones are scattered pretty equally through the clay, which, moreover, is never truly stratified. Again, putting aside the amorphous character of the till, we cannot fail to remark that the great mass of stones and débris which icebergs carry seawards consists almost exclusively of rough, unpolished angular fragments which have tumbled upon the surface of the ice from cliffs and precipices. Many of these, therefore, will show traces of having been exposed to the weather—they

will be more or less altered by atmospheric action; and the same will be the case with the smaller rock-rubbish accompanying them. But the stony till, as we have seen, consists essentially of unweathered materials. The only unweathered and polished or striated stones that an iceberg can possibly steal away with are the few which may have become included in its base before it was shed from its parent glacier, or an occasional boulder that may have worked its way up, as it were, from the bottom in the manner to be described in the sequel. Such being the character of the débris borne seawards upon glaciers, it is evident that the till, with its pell-mell accumulation of polished and striated stones, cannot be of the nature of iceberg-droppings. These are strong reasons for rejecting the iceberg theory of the origin of till or boulder-clay, yet they are not by any means the most cogent, as will be seen by-and-by.

Since till, then, cannot be formed in water and deposited in the same way as gravel and sand—since no such deposit accumulates as a terminal moraine in Alpine valleys, nor can possibly be the result of iceberg-droppings—what other explanation of its origin can be given? To answer this question, we must for a little recall certain other phenomena associated with the till. When that deposit is removed from the underlying rocks, these almost invariably show either a well-smoothed, polished, and striated surface, or else a highly confused, broken, and smashed appearance. But scratched and polished rock-surfaces are by no means confined to till-covered districts. They are met with everywhere and at all levels throughout the country, from the sea-coast up to near the tops of some of our higher mountains. The lower hill-ranges, such as the Sidlaws, the Ochils, the Pentlands, the Kilbarchan and Paisley Hills, the Cheviots, and others, exhibit polished and smoothed rock-faces on their very crests. Similar markings streak and score the rocks up to a great height in the deep valleys of the Highlands and Southern Uplands, and throughout the Inner and Outer Hebrides and Orkney and Shetland the same phenomena constantly recur. The direction of the parallel ruts and striations coincides, as a rule, with the line of the principal valleys. In the Northern Highlands, for example, they keep parallel to the trend of

the great glens; and in the Southern Uplands likewise they follow all the windings of the chief dales and 'hopes.' In the Lowlands, however, their direction does not appear to be influenced so much by the configuration of the ground; for they often cross low valleys at right angles or nearly so, and sweep up and over intervening hills, even when these happen to have an elevation of more than 1,800 ft. above the sea.

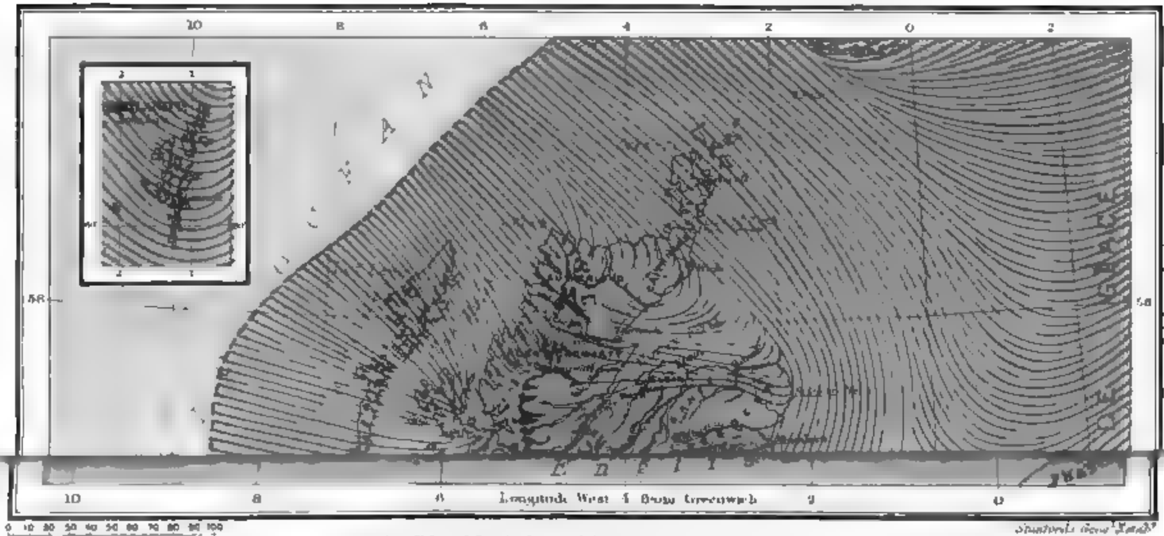
The scratches upon the rocks have exactly the same appearance as those that crowd the surface of the boulder-clay stones; but whereas the striations on the latter may cross and recross, those upon a surface of rock usually run in one and the same direction. Sometimes, however, we meet with exceptions to this rule, when two or even three sets of striæ may be observed upon the same surface of rock. But such cross-hatchings do not occur very often, and seem to be mainly confined to the lowland districts. No one who compares the dressed rocks with the scratched stones can have any doubt that both owe their origin to the same cause. If glacier-ice scratched the stones, then the rocks must have been dressed by the same agency. The work cannot possibly have been done by icebergs, for floating ice has no power to grate along the sea-bottom, so as to polish and dress submarine heights and hollows. The agent that performed the work has actually clung to the ground, and accommodated itself to every inequality of surface—here rounding and smoothing knobs and bosses of rock, there sliding into and polishing dimples and depressions. In short, the appearances tally precisely with what has been observed in the valleys of the Alps and elsewhere. When we have an opportunity of examining the deserted bed of a glacier, we find it smoothed and dressed in every part. Wherever the ice has been able to get at the rock it has ground, scratched, and polished it. Nor can any reasonable person resist the conclusion that the dressed rocks of Scotland have been worked upon by ice in the same way. We must believe that all the hills and valleys were once swathed in snow and ice; that the whole of Scotland was at some distant date buried underneath one immense *mer de glace*, through which peered only the higher mountain-tops. This is no vague hypothesis or speculation founded on uncertain data, no mere conjecture which the

light of future discoveries may explode. The evidence is s clear and so overwhelmingly convincing, that we cann resist the inevitable conclusion. Suppose some visitor wh had only newly arrived in our country were to stumble i the course of his wanderings upon a deserted line of railwa where the old, battered rails gave evidence of having bee well used, he surely would require no reflection to concluc that cars and waggons must frequently have passed alor the line. What would be thought of our visitor's sanity he were to reason in this way:—'Although this looks ve like a railway, with its embankments and rails and sleeper yet I cannot think it is so, for no trains run upon it, and have been here several months, but in all that time ha never seen it used?' Now old embankments and worn-o rails are no more convincing proofs of the former passage wheeled carriages than the smoothed, scratched, and rounde rocks are of the grinding action of old glaciers; and th incredulity that would reject the evidence of the latter mig well be expected to treat the former in a similar way.

Since, then, we must believe that the dressed and rounde rocks could only have been so dressed and rounded by lan ice, it follows that wherever such rock-surfaces occur, the at one time a glacier must have been. Now the scratch may be traced from the islands and the coast-line up to a elevation of at least 3,500 ft.; so that ice must have cover the country to that height at least. In the Highlands th tide of ice streamed out from the central elevations dow all the main glens and valleys; and by measuring the heig attained by the smoothed and rounded rocks, we a enabled to estimate roughly the probable thickness of th old ice-sheet. But it can be only a rough estimate, for long a time has elapsed since the ice disappeared, and ra and frost together have so split up and worn down the roc of these Highland mountains, that much of the smoothin and polishing has vanished. But although the finer mar of the ice-chisel have thus frequently been obliterated, y the broader effects remain conspicuous enough. From a examination of these, we gather that the ice could not ha been less, and was probably more, than 3,000 ft. thick its deeper parts. What wonder, then, that a mass of th

BRITISH ISLES DURING THE EPOCH OF MAXIMUM GLACIATION

Plate I



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bulk, gliding from the mountains down to the sea during a long course of ages, should have left such an impress of its grinding-power upon the rocks that the lapse of thousands of years has not succeeded in removing it. For even when the fine smoothing and polishing have disappeared, the hills yet show in their rounded and flowing outlines that peculiar configuration which is so characteristic of ground over which a glacier has passed.

It is well known that the glaciers of Switzerland are mere pigmies compared to what they have been formerly. The slopes of the Alpine valleys are all smoothed, scratched, and scored up to a considerable height above the present surface of the glaciers; and these smoothed rocks, as in the Engadine, are often separated from the rough, broken, and craggy rocks above by a well-marked line, indicating the height reached by the glaciers in days gone by. But in Scotland such a distinct line of division rarely marks out the upper limits of the glaciation. Frost and rain have made havoc of the ice-work at the higher elevations of the country, and roughened the exposed rocks into crags and peaks.

In the Southern Uplands the ice moved, as in the Highlands, from the central high grounds down all the main valleys; its track being well marked out by an abundant series of finely preserved striæ.[1] From the mountains of Galloway and the uplands of the south-east vast glaciers descended in every direction. The valleys of the Annan, the Nith, and the Dee were filled to overflowing with great confluent glaciers that poured their united volume into the Solway Frith and the Irish Sea. In like manner a vast stream of ice that flowed north-east and then south-east buried the wide vale of the Tweed between the Cheviots and the Lammermuirs.

When the ice-markings are followed into the Lowlands of the central valley, we find that in the vale of the Forth their general tendency is towards the east; while in the lower reaches of the Clyde valley their trend is east, south-east, south, and south-west. The meaning of this apparent confusion is perceived when we trace out the track of the glaciers that issued from the Highlands, and follow the spoor

[1] See map showing the British Isles during the epoch of maximum glaciation: Plate I.

of those that crept down from the Southern Uplands. It then becomes apparent that a great current of ice from the high grounds of Lanarkshire set down the valley of the Clyde, and was met near Glasgow by a vast glacier coming in the opposite direction. Hence the two opposing streams were deflected to east and south-west; on the one hand sweeping across the Lothians into the Frith of Forth and the North Sea, on the other overflowing the uplands of Renfrewshire, and passing south-west into Ayrshire, so as to unite with the glacier masses descending from the Galloway mountains.

Underneath these great streams of ice the whole surface of the country would be subjected to excessive erosion. Hill-slopes would be ground and polished, valleys deepened and smoothed; here the rocks would be finely dressed and striated, there crushed and broken. And what would be the character of the débris that resulted from all this grinding and graving work? In the glaciers of the Alps we have every reason to believe that a considerable proportion of stones used as chisels and stylets by the ice are introduced from above: they tumble from the crags upon the surface of the ice, and drop into those deep crevasses which must sometimes cut a glacier to its bottom. But when ice buried Scotland to a depth of several thousand feet, only a few hill-tops (*Nunatakkr*) would rise above the general level of the *mer de glace*. Consequently little débris would be showered upon the ice; and, even supposing considerable heaps of blocks and rocky rubbish did accumulate here and there at the base of some isolated hill, it is nevertheless very unlikely that any portion would ever work its way to the bottom of the thick ice-sheet. The gravers employed by the ice in dressing the Scottish hills and valleys could not have been derived from above; they must have been obtained from the rocks lying below.

It is quite certain, however, that the ice when it first overflowed the land would find a plentiful supply of loose stones lying upon the ground ready for use. For long ages before the country became locked in ice the climate must have been getting colder and colder. The result of intense frost would be to split up the rocks everywhere; nor would

this be a difficult matter. We must remember that the present deep drift-masses that bury the solid rocks to such a depth had no existence before the advent of the ice-sheet. The rocks then would not be covered with thicker subsoils than is the case in countries where no drift-deposits exist. I have already referred to the heaps of broken rock that cumber the exposed ground in northern and mountainous regions, where whole hills are well-nigh buried in their own ruins. In all arctic and alpine countries, and, indeed, wherever a rock is exposed to the action of frost, it is sure to break up sooner or later. The moraines of the Alps, the enormous ‘ screes ’ of the Himalaya and the Rocky Mountains, and the prodigious piles of débris that collect upon the ice-foot of the Arctic regions, are sufficient evidence of what frost can do.

It is certain, therefore, that when the ice began to creep over Scotland, it would have to make its way through piles of broken fragments and over shattered rock-surfaces. Ice-chisels would thus be prepared for it beforehand, which would aid in the work of dislodging others from the rocks. But as the ice continued to flow outwards in all directions from the dominant heights of the land, it is obvious that sooner or later this preglacial débris, carried forward and spread over a constantly widening area, would come to form a very small proportion of the subglacial accumulation. The larger mass of the materials would consist of unweathered rock-fragments. Here and there, however, some more or less weathered stones and débris might well occur commingled with these, and, under certain circumstances, even the major portion of the materials might be of preglacial origin. As the crushing and grinding continued, few stones would escape being smoothed and striated, while the fine mud resulting from all this work would get mixed up with the stones, and form a stony clay. It is true that water would circulate below the ice to some extent, as we know it does underneath the glaciers of Greenland, and no doubt much glacial silt would be carried away by this means ; nevertheless, all that could possibly escape would bear but a very small proportion to what remained behind. Thus both silt and stones would tend to collect under the ice ; and as that

great mass moved onwards, pressing with prodigious weight, the silt and stones would be squeezed and dragged forward so as to become a confused and pell-mell mixture of clay and stones, with here and there traces of water-action in the form of irregular patches and interrupted bands of stones, gravel, earthy sand, and clay—in short, till, or boulder-clay. Such, then, would appear to be the origin of that remarkable deposit; it is the ground-moraine, or *moraine profonde*, of the old ice-sheet.

The various phenomena exhibited by the till itself are quite in keeping with this conclusion. The very fact that it is generally composed of unweathered rock-material strongly suggests its subglacial origin. Boulders, smaller stones, gravel, grit, sand, and the fine-grained matrix in which these are embedded are all alike fresh—they have not been altered chemically, as would certainly have been the case had they come from superficial sources. It has long been known that the finer-grained material—the clay—of the till is composed of highly comminuted rock-ingredients and the most impalpable powder, dust, and flour of rocks. This rock-meal is unquestionably a mechanical sediment—the result of the grinding-down of minerals and rocks—and consequently it has the same chemical composition as these. Unlike ordinary clay, it is not oxidised. Ordinary clay on the other hand—that, namely, which is formed at the surface of the ground—is the product of the chemical action of acidulated water upon rocks; it is the result of mineral alteration, and therefore has not the same chemical composition as the minerals and rocks from which it has been derived. Careful analyses of the till in the neighbourhood of Boston (Massachusetts), which is exactly comparable to the normal till of the Scottish Lowlands, have led Mr. W. O. Crosby to conclude that during the formation of the boulder-clay 'the operation of the chemical forces at the earth's surface was virtually suspended over the glaciated area.' He found that rock-flour (quartz in a fine state of division) formed by far the larger proportion of the so-called clay of the till. In collecting his samples for examination, all stones exceeding two inches in diameter were excluded, and the average of sixteen analyses gave the following results:—

gravel 24·90; *sand* 19·51; *rock-flour* 43·86; *pure clay* 11·67.[1]

The subglacial origin of the till is further demonstrated by the structural arrangement which it now and again reveals. A study of these leads to the conclusion that the accumulation had a movement of its own under the ice—that it actually flowed with a differential motion, its several ingredients slipping over one another and alongside one another. It was doubtless while they were being pressed and rubbed in the tightly packed but flowing gritty mass that the stones and boulders received their dressing. How thick a stratum of boulder-clay was kept in motion by the ice we cannot tell. It probably varied, but a stage would eventually be reached when the lower part of the deposit, impeded by friction with the underlying rocks, would come to rest. As a rule no strongly marked line would separate the subjacent stationary portion of the till from the sluggishly moving mass above it. There would just be such slight traces of stratification as have been described above (see p. 13). The most conspicuous bedded arrangement is seen in the lee of projecting rocks, where the stones and boulders are drawn out in rudely alternate layers which have a decided dip in the direction of transport. Now and again, however, lines of shearing are visible in the till, which show that the clay occasionally yielded along a definite horizon, and the upper flowing portion was then sharply marked off from the lower stationary mass. The 'lamination' referred to on a previous page must not be confounded with the lamination of an aqueous rock like shale, to which it has only a specious resemblance. It seems to me to be merely indicative of the intense pressure to which the till was subjected during its gradual accumulation. It is comparable, in short, rather to the superinduced 'cleavage' of ordinary roofing-slate than to that original structure which is the result of aqueous sedimentation.

Although the 'stratification' of till is now and again approximately horizontal, it is more usually inclined, curved,

[1] *Proc. Boston Soc. Nat. Hist.* vol. xxv. (1890), p. 115. An examination of the normal till in the neighbourhood of Edinburgh gave me similar results, but the percentage of clay was somewhat higher, ranging from 15 to 17.

or even involved and contorted. From this it may be inferred that, owing to changes in the direction of the ice-flow or in the degree of pressure exerted by it, considerable thicknesses of the subglacial detritus were liable to be disturbed, ploughed up, and more or less re-arranged. This is well seen when the laminated structure is present—the laminæ being often puckered, twisted, and involved; but it is even more conspicuous when beds of sand and gravel and brick-clay are included in the till. These were doubtless accumulated in approximately horizontal positions by subglacial waters—they indicate the existence under the ice-sheet of temporary stream-courses, and of pools and lakes in which water-worn sediment accumulated. When, owing to the collapse of the ice overhead, the subglacial drainage was diverted, boulder-clay again began to accumulate over the site of the old waterways. Sometimes this change was effected without much disturbance of the aqueous sediments, but more usually these were abruptly ploughed through, confused, contorted, bent back upon themselves, and even coiled up and involved with the till.

The 'striated pavements' already described undoubtedly mark definite horizons in the till. It is obvious, in short, that they are glaciated surfaces—that the till in which they are embedded acted the part of solid rock, and was smoothed and graved in the same way as the rock-head itself. There are several ways in which they may be accounted for. We may suppose that the pavements are merely shearing-planes—planes along which the till yielded in the manner indicated above; or they may be 'breaks in the order of succession.' In other words, the boulder-clay in which the pavements occur may belong to one period of glaciation, and the overlying till to another and succeeding period. This is a point, however, which must be considered at a later stage of our inquiry.

It must not be supposed that till was manufactured at one and the same rate over the whole bed of the *mer de glace*. The erosive action of the ice would be largely influenced by the form of the ground across which it moved. Where the gradient induced relatively rapid motion grinding would be most effective, and subglacial detritus would most readily form; where the ground was approximately level and the

ice had free course, it would move more slowly, while its erosive energy would be correspondingly diminished. For the same reasons the thickness attained by the till underneath the ice-sheet would be very variable. It could not collect in any quantity on the steeper gradients, but would tend rather to accumulate in the broad lowland districts where ice-motion was at its minimum.

Some have objected that the moment a layer of till was formed between the ice and the subjacent rock, all wear and tear of the latter would cease, and therefore that the formation of till itself would suddenly come to an end. It would just be as reasonable, however, to infer that all wearing away of a river channel must stop the moment that the channel becomes filled with gravel and sand. But who does not know that the materials in the bed of a stream are continually travelling onward, no matter how slowly? It is quite true that so long as a bank of sand and gravel shall lie in one place, the rock on which it rests will escape the rasp of the river. But the river that piles up such banks will by-and-by sweep them away again, and employ the sand and gravel as agents for wearing down, scouring, and filing the rocks which they formerly protected. And so, no doubt, it must have been with the ice-sheet and its débris. Over many portions of its bed there would be a continual travelling onwards of clay, sand, and stones; while in other areas masses of débris which had collected here and there would be ever and anon ploughed up again, pushed and dragged forward, and compelled to move from one position to another. In this way the underlying rocks would be alternately protected and exposed. That the ice was quite competent to do this work is shown by the enormous size of the blocks of strata and masses of rock which it has dragged out of place. I have referred to the great erratic near Elgin, but better examples are met with on the Continent, as we shall afterwards learn. The rocks of Scotland are not such as could be so effectively quarried in this way. In the sequel it will be shown that masses of rock 400 ft. in thickness have been dislocated and displaced, bent and contorted, by glacial action, while tongues of boulder-clay have been forcibly intruded into the fissures of the ruptured strata.

CHAPTER VI.

ORIGIN OF THE TILL AND ROCK-STRIATIONS AND GROOVINGS OF SCOTLAND—*continued.*

Direction of ice-flow indicated by stones in the till—Cross-hatching of rock striæ accounted for—Intermingling in the till of stones derived fron separate districts—'Debatable land' between rival ice-flows—Local colour ing of till an indication of direction followed by ice-flow—The Ochils Pentlands, and other hills, completely overflowed by ice—Deflections of th ice-flow—Till in upland valleys, why terraced—Origin of lowland 'drums'— Crag and tail, &c.—Islets lying off the coast glaciated from the mainland— Ice filled up all the shallow seas round Scotland—General ice-sheet lik that of the antarctic lands.

THE course followed by the ice-sheet in its downwar progress from the high grounds to the coast is indicated as described in the last chapter, by the directions of scratche and furrows and flutings, and by that peculiar rounded out line which the grinding of the heavy mass has imparted t the mountain-slopes and hill-tops.[1] But even when thes markings do not appear, either on account of the obliteratin effect of weathering, or else because they lie concealed belov a superficial covering of drift, yet the till itself often furnishe evidence as to the direction of ice-flow. If, for example, w know from what part of the country the scratched stones i the till have been derived, it is obvious that we ascertain a the same time the course followed by the ice that brough them. Hence we are enabled to track out the trail of th *mer de glace* over all the country. And it is worthy of not that the evidence supplied by the stones always corroborate

[1] Rocks which are so rounded are known as *roches moutonnées*—a nam probably suggested by a fanciful resemblance to the rounded shape of a sheep back. That part of a glaciated rock which faces the direction from which th ice came is termed the *Stoss-seite* (literally, *pushing-place*); the opposite, lee-side, is the *Leeseite*. When a rock projects prominently above the gener level of a glaciated district it is generally glaciated only, or, at least, mo conspicuously, on the *Stoss-seite*.

that afforded by the *roches moutonnées* and striated rocks. If these last owe their origin to a current of ice that came from the north, then the stones also will be found to have travelled in the same direction. And, curiously enough, in those districts where the rocks exhibit a 'cross-hatching' of striæ, or where the striations on two contiguous rocks do not agree in direction, there also the till shows an intermingling of stones derived from separate districts. Now what does this prove? Clearly this: that the ice-currents were occasionally deflected and forced to go another way. The great stream that crept across the central valley of Scotland was certainly at times turned out of its normal course—now towards the south by the pressure of that powerful current of ice that poured down from the Highlands, and again towards the north when the ice-stream coming from the Southern Uplands

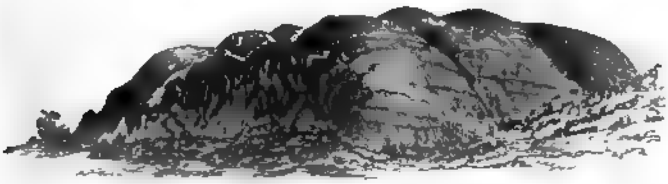


Fig. 21.—Roche Moutonnée.

overpowered and forced back the other; in short, there was a 'debatable ground' between the northern and southern currents, over which sometimes the one and sometimes the other prevailed.[1] The right of possession to the tract of country that lies between Cambuslang and Lesmahagow seems frequently to have been disputed by the rival ice-streams—the rocks of that area being sometimes striated by ice that moved from the north, and sometimes, again, by the confluent masses that flowed from the Southern Uplands. We find also an intermingling of stones—fragments of mica-schist and gneiss from the Highland mountains occurring now and again as far south as Lesmahagow, while stones, apparently derived from the high grounds to the south of that place, appear here and there in the till as far north as

[1] Reference will be made in the sequel to certain instances of cross-hatching, which are to be explained in a different way.

Stonehouse. A similar intermingling of stones from the north and south is seen in the till of the valley of the Esk, near the Moorfoot Hills, in Edinburghshire. But beyond this 'debatable land' striated rocks and scratched stones alike point to a persistent ice-flow in determinate directions. In the near neighbourhood of the Highlands all the stones, without exception, tell of a move outwards from the mountains, and it is the same with rock-striations. The till in the valleys of the Southern Uplands has in like manner invariably been derived from the contiguous high grounds. Following the till from the base of the Grampians, where it is crammed with fragments of slate, mica-schist, granite, gneiss, quartzite, &c., down into the basin of the Forth, we find the number of these Highland stones gradually decreasing, until by-and-by they disappear altogether, or are only met with at rare intervals. And the same is the case with the till that stretches northwards from the Southern Uplands. At first the fragments brought from these uplands are in the majority, but they gradually fall off northwards, until finally we cease to meet with them. It is curious also to notice how the stones lose in size as the parent rock is left farther and farther behind—the longer the distance travelled, the greater having been the degree of crushing and grinding undergone. The local colouring assumed by the till is another strong proof of transportation by land-ice. As described in a previous chapter, this deposit varies both in colour and texture, according to the nature of the rocks near which it lies. Thus it becomes red, and shows a sandy texture in districts where red sandstone is the prevailing rock; but in a region where coal and black shales abound, there we encounter a hard, tough, tenacious deposit, having a dark greyish-blue colour. The reason of this difference is obvious. The clay is derived from the grinding and crushing of the adjacent rocks, and consequently changes its character as the rocks change theirs. But just as some of the included stones not infrequently have been dragged for long distances from their parent rocks, so in like manner has the clay formed in one place travelled onward to another. Hence it often happens that the till of a given district—a red sandstone region, for example—will be found to have invaded and

covered adjoining ground where the rocks are neither red nor arenaceous.

If space permitted, some special proof might be offered in support of a statement already made, namely, that the ice overflowed the hill-ranges and isolated hills of central Scotland. The Ochils, for example, that separate the basin of the Forth from Strathearn are ground off and smoothed in such a way as to indicate that the mass of ice must first have crossed the valley of the Earn from the Grampian Mountains, and thereafter overflowed the Ochils and passed on south-eastwards across the Lomonds and the Cleish hills into the valley of the Forth. The evidence afforded by the till that covers the southern slopes of the Ochils points precisely to the same conclusion, for that deposit is abundantly charged with fragments of gneiss, granite, and other rocks that could only have come from the Highlands. Mr. B. N. Peach found a considerable area of till at a height of 2,200 ft. on the shoulder of Ben Cleugh, and numerous scratched stones occurred on the very top of the hill (2,300 ft.). Similar proof of the passage of land-ice over considerable eminences in the lowland districts might easily be given. For instance, on the very top of Allermuir Hill, one of the highest points in the Pentlands, Dr. Croll got a patch of till containing, amongst other local stones, certain fragments which have been brought from the north or north-west, thus clearly showing that these hills also were overtopped by the *mer de glace*. Again, both rock-scratches and till indicate that the high grounds between Paisley and Kilmarnock have been surmounted by land-ice. According to my brother, Sir A. Geikie, relics of the till are found near the top of Tinto Hill (in Lanarkshire), which rises to a height of upwards of 2,300 ft. above the sea. I have seen till and striated stones lying in the hollows between the tops of the Cheviot Hills at a height of 1,500 ft.

That the ice should have overflowed the land up to such heights will not surprise one; for, by a stream of ice some 3,000 ft. or so in thickness, hills like the Ochils, the Pentlands, and Tinto would be as easily surmounted as stones and boulders are overflowed in the bed of a river. And yet, just as these boulders will deflect that portion of the river's

current that strikes upon them, so the heights to which I refer appear to have partially turned aside the stream of ice that moved against them. This is shown by the manner in which the flutings and groovings bend round the sides of a hill before they finally cross it and resume their normal direction.

The flutings and groovings in the valleys of the Southern Uplands show distinctly that the ice to which they owe their origin not only filled the valleys, but swept across the intervening hills. The markings referred to run in a nearly horizontal direction along the steep slopes of the hills, so that they appear to rise as the valley descends; and thus, while we follow the stream, they gradually mount higher and higher until the crest of the hill is reached over which they eventually disappear. The beautiful valley of the Yarrow, below Gordon Arms Inn, affords a fine example of the phenomena in question.

Reference has already been made to the unequal distribution of the till. It lies thickest in the valleys, and thins away towards the hills, being found for the most part in patches when we get above a height of 1,000 ft. In the hilly districts of the south of Scotland it occurs chiefly in the bottoms of the valleys, but it may sometimes be met with nestling in hollows even up to a height of 1,800 or 1,900 ft. The whole appearance of the deposit, however, shows that it never did attain any thickness at these heights, the force of the ice-stream on steep slopes and exposed places having prevented its accumulation, just as a river will not allow sediment to accumulate upon the tops and exposed sides of the large boulders in its bed. But in the lower reaches of the upland valleys, notably in Peeblesshire, the till often attains some depth. It gradually lessens, however, as we trace it towards the heads of the valleys, where it eventually disappears. The general aspect presented by the deposit in these valleys is that of a flat-topped terrace inclining gently from the hill-sides and sloping gradually down in the direction followed by the stream, at about the same angle as the bottom of the valley itself. I believe that this terrace-like appearance of the till was most probably assumed underneath the ice-sheet. In narrow and deep hollows, like the upland

valleys, the ice was not liable to such deflections as took place over the 'debatable grounds'; and the till forming below it consequently escaped being squeezed to and fro; the valleys were filled with streams of ice flowing constantly in one and the same direction, and the probabilities are therefore that the débris which accumulated below would be spread out smoothly. In the Lowlands the effect produced by the varying direction and unequal pressure of the ice-sheet is visible in the peculiar outline assumed by the till. Sometimes it forms a confused aggregate of softly-swelling mounds and hummocks; in other places it gives rise to a series of long smoothly-rounded banks or 'drums' and 'sowbacks,' which run parallel to the direction taken by the ice. This peculiar configuration of the till, although doubtless modified to some extent by rain and streams, yet was no doubt assumed under the ice-sheet—the 'sowbacks' being the glacial counterparts of those broad banks of silt and sand that form here and there upon the beds of rivers. Perhaps the most admirable example in Scotland of this peculiar arrangement or configuration of the till occurs in the valley of the Tweed, between the Cheviot Hills and the Lammermuirs. In this wide district all the ridges of till run parallel to each other, and in a direction approximately east and west. This, too, is the prevailing trend of the rock-striations and *roches moutonnées* in the same neighbourhood.

The phenomena of 'crag and tail' afford yet another indication of the path followed by the ice. A familiar illustration of the mode in which 'crag and tail' have been formed may be obtained by placing a large stone in the current of a stream, and watching the effect produced upon the carriage of sediment by the water. The current sweeps against the stone, and is deflected to right and left—there being of course considerable commotion in front and quiet water behind. The current thus stemmed is forced downwards with a stronger pressure upon the bed of the stream by the water continually advancing from behind, and the result is that a hollow is gradually scooped out in front of the stone, and for some way along its sides. In the rear, where there is comparatively little stir in the water, silt and sand speedily accumulate, until a long sloping 'tail' is

formed, stretching away from the stone for as great a distance as the quiet water extends. If for a stone we substitute a big crag, standing up in a broad valley, and for the little stream of our illustration a deep current of land-ice, we shall have no difficulty in understanding the origin of 'crag and tail.' In the valley of the Forth, where isolated hills and bosses of rock are not uncommon, the till is invariably heaped up on the east side of the crags, showing that the set of the ice-stream was from west to east; the direction in which the till has travelled, and the course followed by the rock-striations, both lead us to the same conclusion.

Thus on every hand we are furnished with abundant proof of the former existence of a great *mer de glace* in Scotland. From the tops of some of the higher mountains down to the edge of the sea, no part of the country has escaped abrasion. The hills are worn and rounded off, and the valleys are cumbered with the wreck and ruin of the rocks. Nay, the islands which lie off the coasts plainly indicate by striations and other glacial markings that ice has swept over them also. They are smoothed not from the centre to the circumference as would have been the case had they supported independent ice-sheets, but the striations go right across them from side to side. It cannot be doubted therefore that the ice, to the grinding action of which these striations are due, actually crossed from the mainland over what now forms the bed of the sea. The glaciation of the Outer Hebrides affords a striking example. These islands have certainly been traversed by ice that streamed out from Skye and the mainland. The *mer de glace* was sufficiently deep to fill up the Minch (50 to 100 fathoms in depth), and to drown all but the tops of the highest mountains of Lewis, Harris, and South Uist on its passage outwards to the Atlantic. (See Plate IV.) From the Butt of Lewis to Barra Head the islands everywhere bear traces of severe glaciation —the only points which have escaped being those that exceed a height of 1,500 or 1,600 ft. The more or less isolated mountains are merely huge *roches moutonnées*. Thus Suainabhal (1,300 ft.), a conspicuous hill rising to the south of Loch Roag, near the west coast of Lewis, is ice-worn from base to summit. The view from the top of this

mountain is wonderfully impressive; indeed there is no district in Scotland where the intensity of the old glaciation is better exhibited. The whole country to north and east, far as eye can reach, shows the most evident marks of having been swept and ground by a great glacier. One sees everywhere a mammillated surface. Round-backed rocks, hummocks, and hills bare of drift and soil, with countless pools and lakelets nestling in their hollows, impart to the region a character of great desolation, strongly recalling similar scenes in Finland and the north of Norway.

Taking 1,600 ft. as the thickness of the ice that overflowed the lowest ground of the Outer Hebrides, and 3,500 ft. as the probable upper limits of the *mer de glace* in Western Ross and Sutherland, we can readily estimate the depth of the ice-sheet that filled up the Minch. Immediately off the east coast of Harris the thickness of the ice would be upwards of 2,400 ft., for the sea there has a depth of 121 fathoms. In the centre of the North Minch the upper surface of the *mer de glace* would be 2,550 ft. above what is now the sea-level, the actual thickness of the ice being 2,850 ft. Nearer the shores of the mainland, in the Inner Sound, the depth attained by the ice would be still greater, not less than 3,800 ft. Measuring from the Cliseam in North Harris to the mountains of Torridon, we have a distance of 56 miles, so that the inclination of the surface was very little, the fall not being more than 35 ft. per mile.[1]

It is needless to say that the islands of the Inner Hebrides afford like evidence of having been more or less drowned in the ice that streamed out from the mainland. The lofty Coolin Mountains of Skye, it is true, formed of themselves a centre of dispersion, but the northern parts of the island were overflowed by the ice that crept out from the great glens of Ross. The smaller islands, however, were completely swept over, like so many boulders in the bed of a stream. Thus I found a vertical face of rock, within a few feet of the highest point of Colonsay, distinctly smoothed and striated.[2]

[1] *Quart. Journ. Geol. Soc.* 1878, p. 861.
[2] *Trans. Geol. Soc. Glasgow*, vol. vi. p. 162.

In like manner the Island of Bute has been scored and smoothed from end to end by a mass of ice which, streaming out from the highlands of Argyleshire, filled up the Kyles, and then passed southwards over the whole island to occupy the bed of the Frith of Clyde between Bute and Arran. Again, it may be mentioned as a very striking fact that the lofty cliffs along the south-west coast of Ayrshire are striated along their tops in a direction parallel to the trend of the coast—that is, from north-east to south-west. An examination of the map (Plate I.) will show how these striations have been produced by a mass of ice that filled up the bed of the adjacent sea, and streamed south-west towards the northern coast of Ireland. From these and similar facts geologists have been inclined to infer that at the time the *mer de glace* covered Scotland the whole of our country stood at a higher level relative to the sea than now; in other words, that a large part of what in these days forms the floor of the sea was at that time in the condition of dry land. This being so, the ice from the central parts of the country would creep outwards and overflow what are now islands, in the same way as it surmounted the Ochils, the Pentlands, and other hill-ranges of central Scotland. Now such may quite well have been the case, and there are indeed good grounds for believing, as we shall afterwards see, that, in times anterior to the advent of the Ice Age, Scotland did really stand at a higher level above the sea than now. There is no proof, however, that the greater elevation of the land in preglacial times (amounting, as far as we can show, to some 300 ft. only, although it may have been as much as 600 ft.) had anything whatever to do in bringing about a glacial period. All we know is that before the Ice Age began the Scottish shores extended considerably farther out to sea; but the sea may have gained upon the land again, and may even have reached to a greater height than it does now, when the vast glaciers commenced to creep out from the mountain-valleys upon the low grounds. The presence of a considerably deeper sea than that which now flows round Britain could not have availed to stay the onward progress of the thick land-ice; so far as that goes, therefore, it is not necessary to infer, as some have done, that in early

glacial times our land stood at a much higher level, and that the sea-bottom between Scotland and the outlying islands then existed as dry land. If the old glaciers entered the sea at a time when the relative level of land and sea was much the same as it is at present, they could not have had any difficulty in making their way from the mainland to the islands. A mass of ice, upwards of 2,000 ft., and in parts attaining 3,000 ft. in thickness, would fill up every fiord-valley, and dispossess the sea in all the sounds, straits, and channels that separate the islands from themselves and the mainland. A glance at the Admiralty charts will show how this could be. From them it will be learned that, between the mainland and the islands, the sea seldom attains a greater depth than 70 fathoms, or 420 ft., and even this depth is quite exceptional. The North Sea, between England and the coasts of France and the Netherlands, does not average more than some 150 or 160 ft. in depth: and the soundings show that the water deepens very gradually northwards. To reach the 100-fathoms line, we approach quite close to the coast of Norway, and the same line lies considerably north of the Shetland Islands, from which it sweeps west by south, keeping outside of the Hebrides and Ireland. In no part of our seas, then, could the water have been of sufficient depth to float those prodigious masses of ice which we can prove were generated in Scotland during the glacial period. Before ice will float, it requires water deep enough to accommodate some seven or eight parts of its bulk below the surface of the sea; and therefore, as Dr. Croll upwards of twenty years ago was the first to point out, the Scottish *mer de glace* must have advanced over the bed of the North Sea to coalesce with the great ice-sheet which at the same time crept out from Norway.[1] This acute inference was subsequently proved to be correct by the observations of Messrs. Peach and Horne, who showed that the Orkney and Shetland Islands had been overwhelmed by the united Scoto-Scandinavian *mer de glace*.[2] But the evidence which had led geologists to conclude that the whole basin of the North

[1] *Geological Magazine*, vol. vii. (1870), p. 209.
[2] *Quart. Journ. Geol. Soc.* 1879, p. 778; 1880, p. 648; *Geol. Mag.* 1881, p. 65; *ibid.* 1881, p. 364; *Proc. Royal Phys. Soc.* vol. vi. p. 316.

Sea was formerly filled with glacier-ice will be discussed in the sequel.

To return to the conditions that obtained in the west of Scotland at the climax of glaciation, it is obvious that the ice-sheet which overwhelmed the Outer Hebrides must have extended for some considerable distance out to sea, where it would at last terminate in precipitous or vertical cliffs. How far westward it would flow into the Atlantic would, of course, depend entirely upon its thickness and the depth of the sea. If it retained at its outskirts only one-third of the great depth under which it buried central Scotland, it must have gone out as far at least as the 100-fathom line—supposing the sea to have been as deep then as it is now. Sir J. C. Ross's striking account of the mighty ice-sheet under which so much of the Antarctic land lies buried gives one a very good notion of the kind of appearance which the skirts of our own ice-sheet presented. After reaching the highest southern latitude which has yet been attained, all his attempts to penetrate farther were frustrated by a precipitous wall of ice that rose out of the water to a height of 180 ft. in places, and effectually barred all progress towards the pole. For 450 miles he sailed in front of this cliff, and found it unbroken by a single inlet. While thus coasting along, his ships (the *Erebus* and *Terror*) were often in danger from stupendous icebergs and thick pack-ice, that frequently extended in masses too close and serried to be bored through. Only at one point did the ice-wall sink low enough to allow of its upper surface being seen from the masthead. Ross approached this point, which was only some fifty feet above the level of the sea, and obtained a good view. He describes the upper surface of the ice as a smooth plain shining like frosted silver, and stretching away far as eye could reach into the illimitable distance. The ice-cliff described by Ross is the terminal front of a gigantic *mer de glace*, which, nurtured on the circumpolar lands, creeps outward over the floor of the sea until it reaches depths where the pressure of the water stops its further advance by continually breaking off large segments and shreds from its terminal front, and floating these away as icebergs. And such must have been the aspect presented by the margin of

Fig. 22 Antarctic Ice-sheet, after Sir J. C. Ross. (H. M. Skae.)

the old ice-sheet, which, in the early stages of the glacial period, mantled Scotland and its numerous islets, filling up the intervening straits and channels of the sea, and terminating far out in the Atlantic Ocean in a flat-topped vertical cliff of blue ice. (See Fig. 22.)

CHAPTER VII.

BEDS SUBJACENT TO AND INTERCALATED WITH THE SCOTTISH TILL.

Lower and upper till or boulder-clay.—Upper deposit most abundantly met with—Beds in and below till—Seldom seen except in deep sections—Examples of superficial deposits passed through in borings, &c.—Sections exposed in natural and artificial cuttings—Examples—Beds contorted and denuded in and below till—Examples—Fossiliferous fresh-water beds in the till—Examples—Fossils in the till—Striated pavements of boulders in till.

THE reader who has accompanied me so far may remember that, while describing the till, I mentioned that sometimes it was underlaid by deposits of gravel, sand, silt, mud, brick-clay, and peat, and that occasionally similar deposits rested upon it and were themselves covered by an upper accumulation of till or boulder-clay. And I stated that the upper deposits of till often differed from the lower in being somewhat less firm and tough, while at the same time they not infrequently contained a greater proportion of angular unpolished stones and very large blocks and boulders. Generally, however, the upper till is quite as tenacious, tumultuous, and amorphous as the lower, and thus, in many cases, it is very difficult to distinguish the one from the other; indeed, in isolated sections where only one till is exposed it is often quite impossible to say which it may be. My own impression is that most of the boulder-clay visible at the surface of the ground throughout the length and breadth of the country is not the oldest accumulation of that kind, as will appear obvious enough after we have completed our examination of those subjacent and intercalated beds of gravel, sand, &c., which I am now about to describe. In the interior of the country we can only be sure that we are looking at lower or upper till when the two deposits appear in

one and the same section, which is not a very uncommon occurrence. As a rule, when such is the case, we find them separated by intervening layers of sedimentary materials which may vary in thickness from a mere line up to many feet or yards. Occasionally, however, the upper boulder-clay rests directly upon the lower, but there is always a more or less well-marked line of division between the two—the surface of the bottom bed being frequently irregular and hummocky. In maritime regions it often happens that the upper till contains, scattered throughout its mass, more or less numerous sea-shells, of arctic, northern, and common British species, which, as a rule, are broken, crushed, and even striated, although perfect single valves and univalves are sometimes met with. Notwithstanding its fossiliferous character this till is usually just as tumultuous a deposit as any lower or upper till of the interior. No such shelly tills are found in the inland districts. We shall see by-and-by, however, that arctic sea-shells do occasionally occur in beds of clay and sand that either underlie, or rest upon and are covered by separate masses of till in which no marine organisms can be detected.

For the present, however, I shall reserve all consideration of the shelly tills and other boulder-clays, which either overlie or contain marine fossiliferous deposits, and shall confine attention in this and the three following chapters to those beds of gravel, sand, clay, silt, and peat, which are of *fresh-water* origin, and which are associated (either as subjacent or intercalated deposits) with accumulations of till in which *no marine organisms* appear.

The subjacent and intercalated beds which we now proceed to examine not infrequently yield organic remains, and when such is the case we can usually be in little doubt as to the mode of their origin. It is otherwise, however, with the water-assorted beds in which no fossils appear. In most cases such unfossiliferous deposits are probably of subglacial origin—they point to the action of water flowing underneath the ice-sheet, and are therefore of the same age as the till itself. Some of the more massive accumulations, however, which occur underneath or intercalated between two sheets of till would appear to have formed in true glacial lakes—

sheets of water dammed back by glacier-ice. All such infra- or intra-glacial deposits, whether fossiliferous or not, occur somewhat partially, the till in many districts not showing any such intercalations, but this seemingly partial distribution is more apparent than real. In the upper reaches of the valleys, where the top-covering of till is not often thick, the streams are able to cut down through this to the solid rocks, and thus expose any intercalated beds of gravel and sand or clay which the till may chance to contain. But where the valleys widen out into the broad undulating lowlands, there are few natural sections to disclose completely the character of the superficial accumulations. Many of the streams do not get through the till to the underlying rocks, so that we cannot always be sure from the sections seen that the boulder-clay may not contain or overlie beds of sand, silt, and gravel. In such low-lying districts, too, railway-cuttings do not often go deep into the deposits, so that we obtain comparatively little aid from them either. So long as we have only a partial exposure of the glacial series, and not a complete section from the surface down to the subjacent pavement of rock, we are not entitled to assume that the whole superficial covering consists of till, merely because that deposit may chance to be the only one visible at the surface. The results obtained from a number of careful borings should render us cautious in this matter; for in several districts where the superficial covering might have been considered to consist wholly of boulder-clay, that deposit appearing everywhere over the entire surface of the ground, the boring-rods have, nevertheless, after piercing the till, gone down through considerable depths of sand, gravel, and other materials. At the risk of tediousness I shall here jot down a few records of such borings, that the reader may compare them with the sketch-sections.

The two examples that follow show the occurrence of beds (probably of subglacial origin) underlying one single mass of till. The first is from the valley of the Lugar, near Old Cumnock, Ayrshire :—

	Ft.	In.
Strong blue till with stones [till]	76	0
Brown sand, very fine	3	6
Gravel and stones with large 'whin' boulders	7	0
Rock.		

The next is the record of a boring made at Woodhall, ne Ormiston, Midlothian:—

	Ft.	In.
Surface soil	2	0
Clay and stones [till]	4	0
Sand and channel [gravel]	6	0
Sandy shales, &c.		

The succeeding show a greater variety in the superfici accumulations. The localities from which they are tak are given within brackets:—

[ELPHINSTONE, MIDLOTHIAN.]

	Ft.	In.
Surface soil	1	0
Clay	5	0
Clay and stones [till]	4	0
Channel [gravel]	4	6
Sand and channel [gravel]	5	6
White sandstone.		

[WOODHALL, MIDLOTHIAN.]

	Ft.	In.
Surface soil	1	0
Clay and stones [till]	17	0
Sand and channel [gravel]	13	10
Sandstone	2	11
Channel [gravel]	2	7
Clay and stones [till]	1	4
Sandy shales, &c.		

[FROM PIT AT ORBISTON, LANARKSHIRE, MOSSEND IRON COMPANY.]

	Ft.	In.
Surface soil	1	0
Red till and stones [till]	36	6
Sand and gravel	4	0
Dark muddy sand	21	8
Brown sandstone in beds	28	0
Whinstone block	0	10
Sand and gravel	4	9
Whinstone block	0	3
Sand and gravel	1	5
Light sandstone		

[BORING, DYKEHEAD, LARKHALL, LANARKSHIRE.]

	Ft.	In.
Sandy clay and stones [till]	24	0
Sand and gravel	5	6
Sandy mud	38	6
Tough clay and stones [till]	33	0
Mud	7	0
Sand	11	0
Sandstone block	4	0
Sand and gravel	12	0
Sandy clay	3	0
Soft mud	30	0
Soft mud and beds of sand	5	0

[BORING, IN SAME DISTRICT AS LAST.]

	Ft.	In.
Surface and soft sandy clay	**5**	**0**
Soft clay	**13**	**0**
Sand	**3**	**0**
Mud	**24**	**6**
Gravel and sand	**25**	**6**
Stiff clay and stones [till]	**14**	**6**
Sand	**4**	**6**
Sand and gravel	**16**	**6**
Sandy clay and stones [till]	**2**	**0**
Mud	**8**	**0**
Muddy sand	**17**	**0**
Hard gravel	**3**	**6**
Stiff sandy clay and stones [till]	**10**	**0**
Mud	**22**	**6**
Mud with broken 'metals'	**7**	**6**
Carboniferous strata.		

I shall have occasion presently to refer to these 'borings,' and to adduce others; meanwhile enough have been given to show that shallow stream-sections, and other natural and artificial exposures, do not always tell us the whole truth. Anyone going over the ground from which some of these borings are taken could not possibly have guessed that underneath the till, or other deposits he saw at the surface, lay deep beds of sand, gravel, mud, and intercalated masses of till.

But although stream-sections never yield such deep exposures of drift as some of the above, yet the cuttings laid open by the rivers are often highly instructive. And so often do the river-cuts disclose the presence of sand, mud, and gravel intercalated amongst or underlying till in the Lowlands, that we must look upon the occurrence of these beds rather as the rule than the exception. It must not, however, be imagined that the beds referred to always, or even often, attain the great thickness indicated in some of the borings given above. They are generally much thinner, and frequently absent altogether, when nothing save sheer till covers the underlying rocks. This is most commonly the case in the hilly districts, the subjacent and intercalated beds becoming more frequent, extending more continuously, and acquiring a greater thickness as they approach the lower levels of the country. Yet, even in these last-named districts, they seldom continue far without interruption, but ever and

anon disappear, leaving the stony clay to form the whole of the covering down to the rock-head.

I shall now bring forward a few sections to illustrate the general aspect of the till and its associated deposits as presented to us in natural and artificial cuttings. The first I select, not only as an example of the occurrence of beds underneath the till, but also because it serves to show the

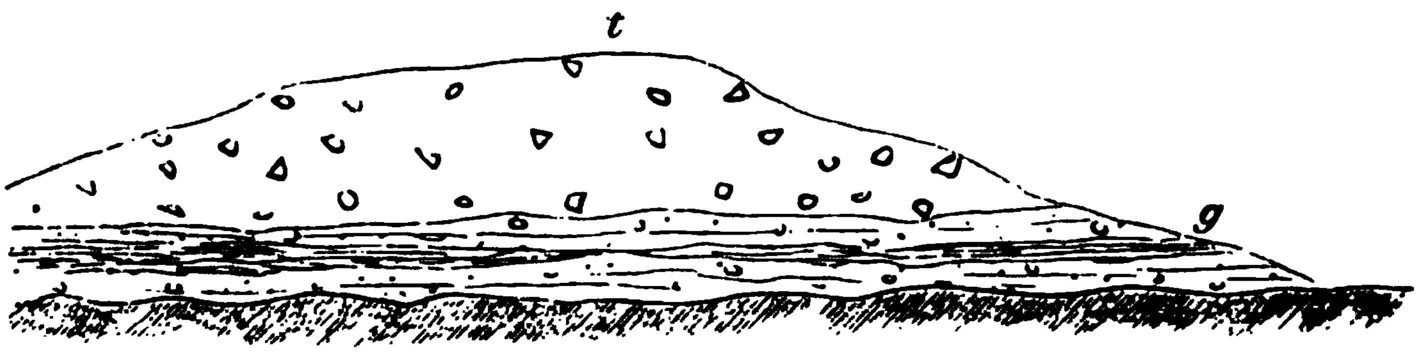


Fig. 23.--Till, *t*, resting on stratified deposits, *g*: Douglas Burn, Yarrow.

general position occupied by the till in the valleys of the Southern Uplands.

Fig. 23 represents the section as seen in the left bank fronting the stream; Fig. 24 represents the same deposit as it would appear in a transverse section; thickness of deposits 10 to 15 ft. The water-assorted beds are most probably of subglacial origin.

A fine example of similar phenomena was pointed out to

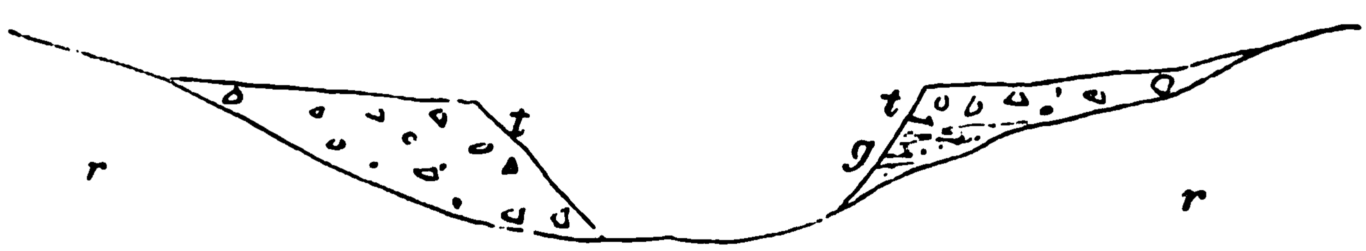


Fig. 24.—Section across Douglas Burn, Peeblesshire.

me by my colleague, Mr. B. N. Peach, in the north bank of the river Tweed, near Melrose. The annexed Fig. 25 will convey a general idea of the appearance of the beds. The rocks, *r*, were smoothed as if water-worn below the coarse shingle and gravel, *g*, and from the arrangement of the gravel there could be no doubt of its fluviatile or torrential origin It was probably laid down in front of the advancing ice, which subsequently covered the deposits with its bottom-moraine.

It frequently happens, however, as I have remarked above, that the stream-sections do not go down quite to the rock. In such cases, although we may sometimes surmise what the

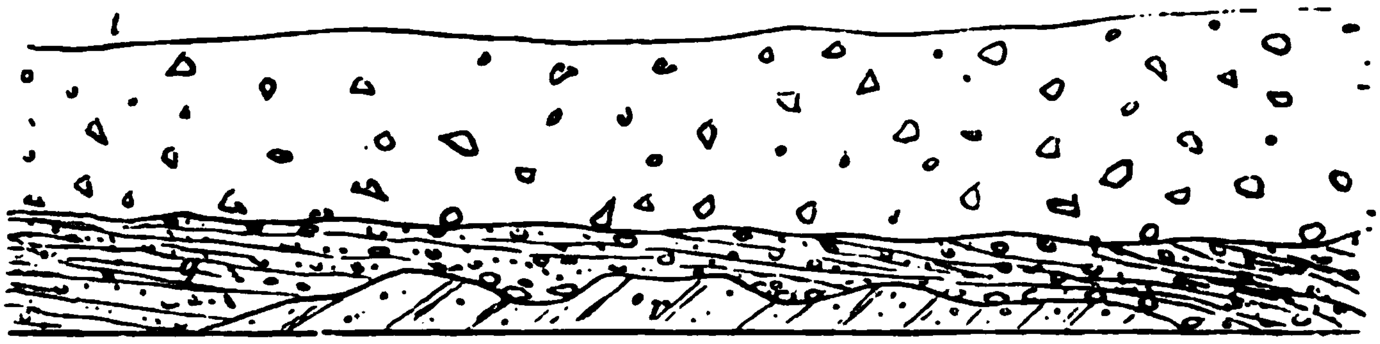


Fig. 25.—Till, *t*, on river-gravel and sand, *g*: Tweed, Melrose (thickness, 30 to 40 ft.).

underlying drifts are, yet we never can be at all sure—so inconstant are they, so liable to change. In the sections that follow it will be observed that the subjacent rock is not

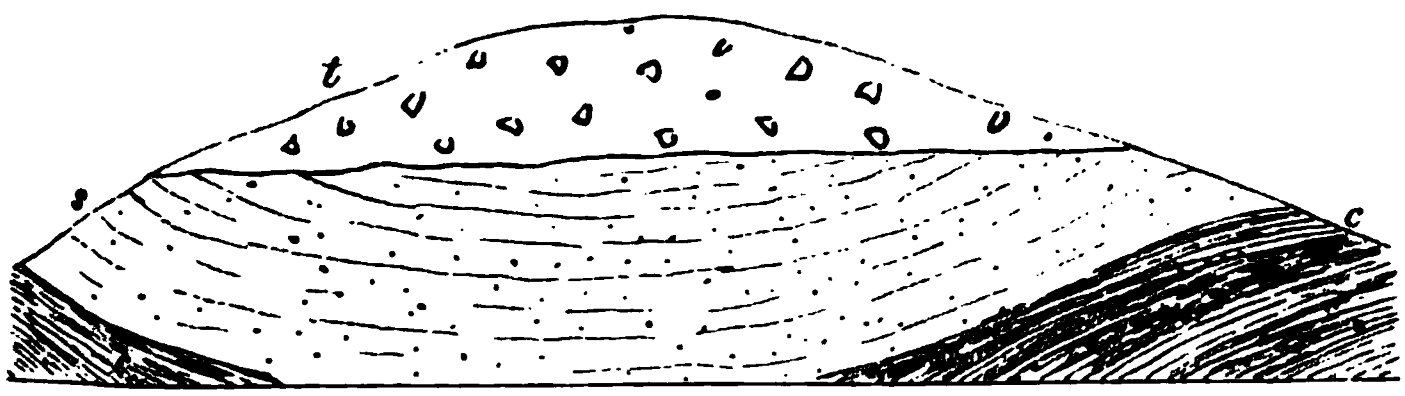


Fig. 26.—Till, *t*, on stratified deposits, *s c*: Glen Water, Ayrshire (thickness, about 30 ft.).

seen, and therefore we cannot say whether the aqueous deposits that underlie the till form the bottom beds of the drift or not.

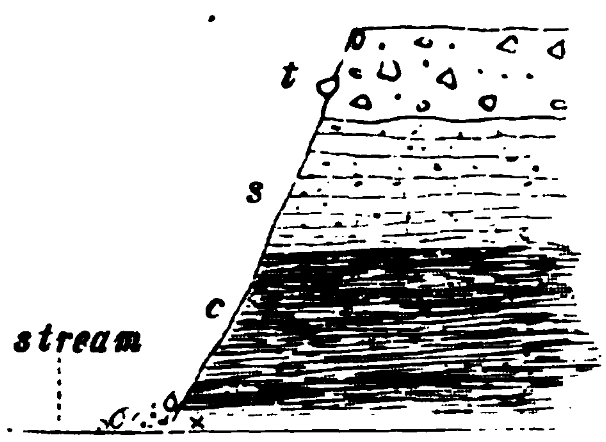


Fig. 27.—Till, *t*, resting on sand, *s*, and clay, *c*: Garpal Water, Ayrshire.

In this section (Fig. 26) a bed of strong tough till rests upon a fine yellowish white sand, *s*, containing thin lines or laminæ of brownish clay. Underneath the sand comes fine clay, *c*, arranged in leaves, with partings of sand. It is

worth noting also that a few well-scratched stones are scattered sparsely through the beds last mentioned. There can be little doubt that these water-assorted beds, and the similar accumulations which are shown in Fig. 27, are of lacustrine origin, and were probably accumulated in ice-dammed waters.

In the sections now given it will be observed that the till rests upon a plain or level surface of sand, gravel, or clay

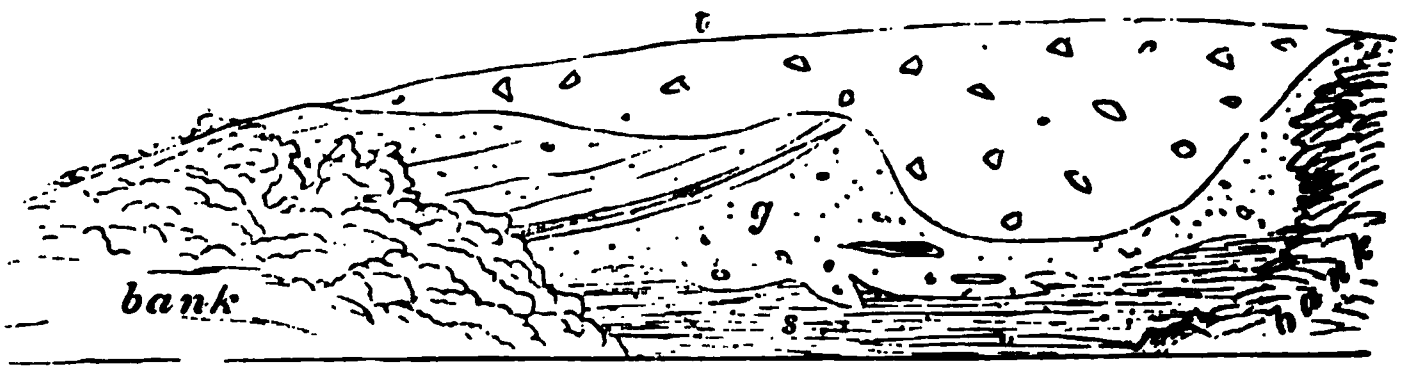


Fig. 28.—Till, *t*, cutting into stratified deposits, *g*: river Clyde, near Covington.

as the case may be. The junction-line, however, is not always or even often so regular. In Fig. 28 the till is represented as cutting down into beds of sand and gravel in a most irregular way—the lines of bedding in these deposits ending abruptly against the till. A still better example of the same appearance was exposed during the progress of the excavations for the Peebles Railway at Neidpath Tunnel.

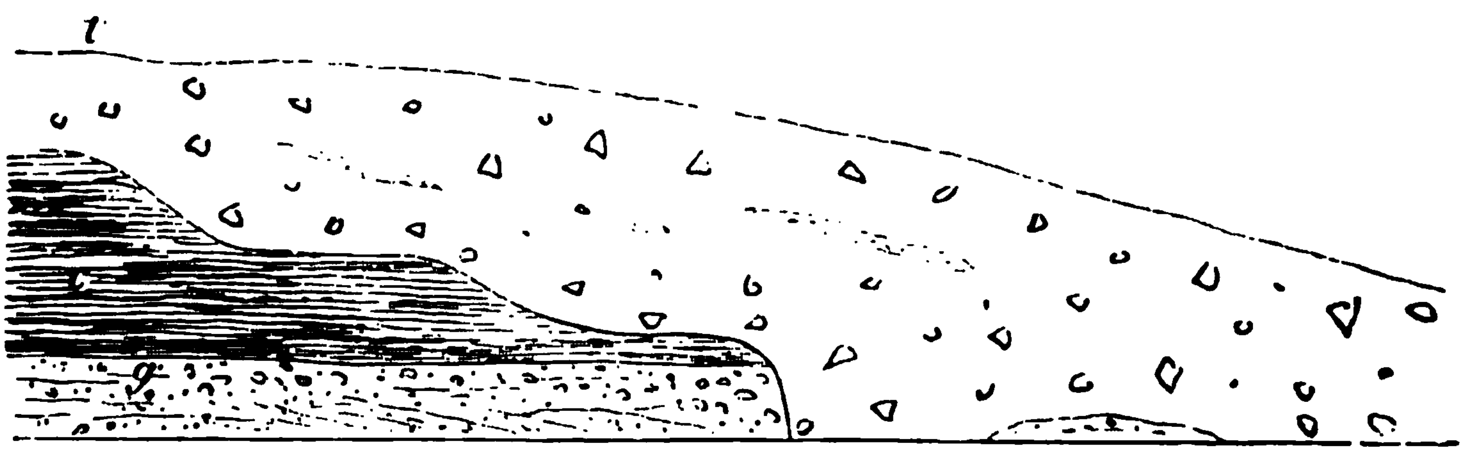


Fig. 29.—Till, *t*, cutting down into stratified deposits, *c g*: Neidpath, Peebles (thickness of drift, 40 to 50 ft.).

Here a mass of tough till, *t*, with the usual scratched stones overlies a series of horizontal beds of clay, sand, and gravel (*c*, *g*), which terminate quite suddenly against the till. The clays were of that kind which is termed 'gutta-percha,' exceedingly fine, and arranged in extremely regular layers or laminæ, underneath which were earthy gravel and sand.

Only one bed of till is shown in the above sketch-sections,

but underneath the aqueous beds represented in Fig. 29 I have reason to believe that another deposit of till occurs. In the next illustration (Fig. 30) two beds of till are apparent. The intercalated beds here consist of sand and clay. They are capped by till, t^2, somewhat sandy, but quite unstratified and full of striated stones; a more tenacious mass of till, t^1, underlies the intercalated beds, which are

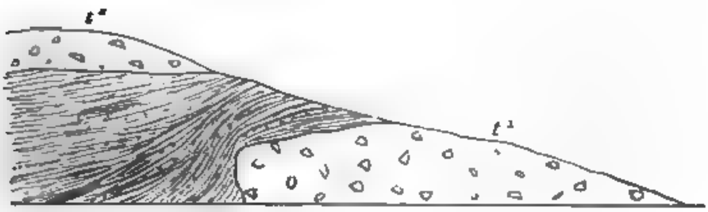


Fig. 30.—Stratified beds, *c s*, intercalated with till, t^1 t^2: Glen Water, Ayrshire (25 to 30 ft.).

standing nearly on end, and form a most irregular junction with the till upon and against which they rest.

Another example (Fig. 31) of somewhat similar phenomena I take from the eastern side of the country. In both these sections the crumpling up of the beds below the upper deposit of till is very marked. Other examples might easily be given, but from those already produced the reader

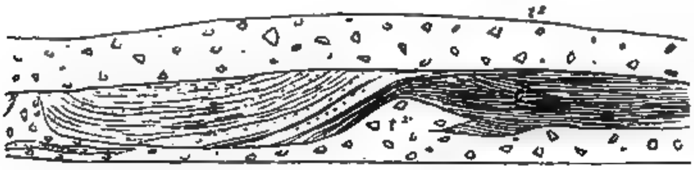


Fig. 31.—Stratified beds, *s c*, in till, t^1 t^2: Leithen Water, Peeblesshire.

will have a clear enough notion of what is meant by the contortion and displacement of the beds in the till.[1]

The sections to which I shall now refer are most interesting, inasmuch as they have yielded organic remains. Many years ago my brother described a section of till seen in the

[1] For a further account of beds subjacent to or intercalated among till, the reader who is interested in the matter may refer to my brother's paper on the 'Glacial Drift of Scotland' (*Trans. Geol. Soc. Glas.* vol. i. part. ii.), in which he will find references to other papers descriptive of the same phenomena.

Slitrig Water, near Hawick. Professor Young and I saw the section at the same time, which is given by my brother as follows :—

Vegetable soil.
Boulder clay, 30 to 40 ft.
Stratified beds. { Yellowish gravelly sand.
Peaty silt and clay.
Fine ferruginous sand.
Coarse shingle, 2 to 3 ft. }
Coarse stiff boulder-clay, 15 to 20 ft.

It may aid the reader's conception of this succession if I give here a diagrammatic section across the deposits, which will show at the same time the position of the intercalated beds, and the mode in which the till occurs in the valley. 'The cliff at this locality' (I quote from my brother's paper)

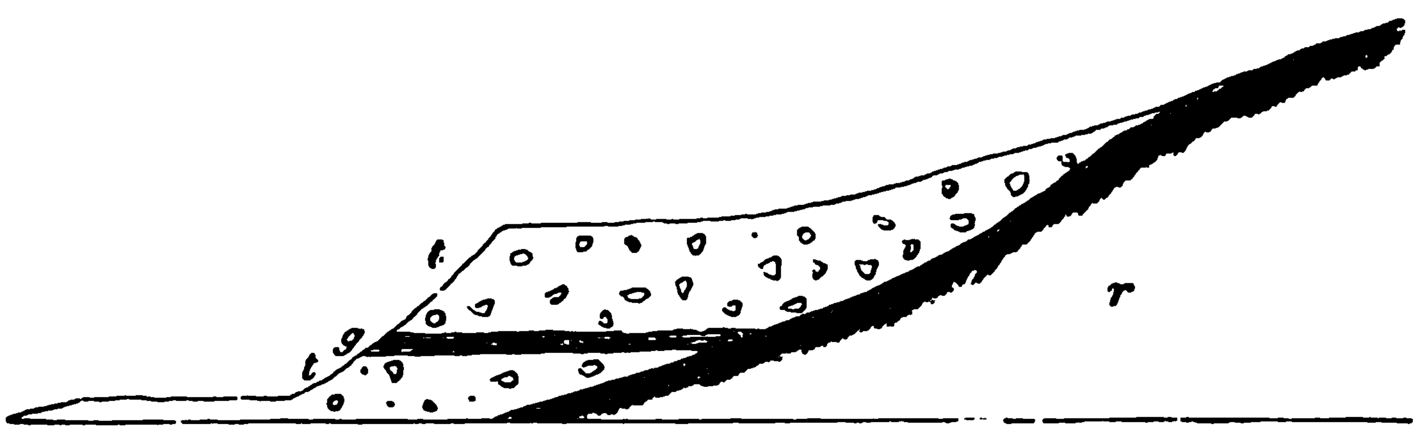


Fig. 32.—Fossiliferous beds in till : Slitrig Water, near Hawick. *t*, till ; *g*, stratified deposits ; *r*, rock.

'is at least forty or fifty feet high, and consists of a stiff bluish clay stuck full of boulders. The bed of stones or shingle is well seen, even at a little distance, running as a horizontal band along the face of the cliff at a height of some fifteen or twenty feet above the level of the stream. On closer examination this zone proved to consist not merely of water-rolled shingle : over the lower stratum of rounded stones lay a few inches of well-stratified sand, silt, and clay, some of the layers being black and peaty, with enclosed vegetable fibres in a crumbling state.' 'So far as it was possible to ascertain the nature of the vegetable remains in the peaty layer, they appeared to be the rootlets of a kind of heath.'

On the banks of the Carmichael Water, Lanarkshire, according to the same observer,[1] beds of sand, clay, silt, and

[1] *Trans. Geol. Soc. Glas.* vol. i. part ii. I have seen the sections described.

gravel, with a thin peaty layer, and fragments of mouldering wood, rest in a hollow of the till, and are covered up by another mass of exactly the same kind of deposit.

Again, he describes certain contorted beds of tough gutta-percha clay and finely stratified sands as occurring in the till at Chapelhall, near Airdrie. These deposits varied in thickness up to twenty or thirty feet, and in them layers of peat and decaying twigs and branches have been detected. They were clearly overlaid and underlaid by tough stony till.

At Hailes Quarry, two miles west of Edinburgh, some interesting sections have been from time to time exposed.

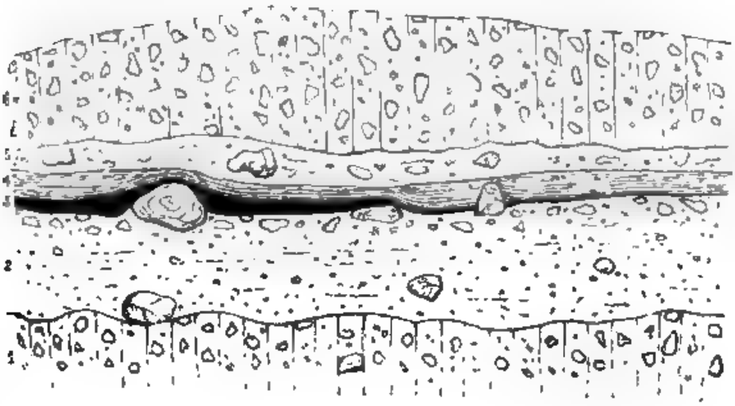


Fig. 33.—Section of glacial and interglacial deposits; Hailes Quarry, near Edinburgh.

In 1878 a good cutting showed the succession of deposits represented in Fig. 33. The lower boulder-clay (1) was the usual dark greyish blue till met with in the district. Above it came an irregular bed of coarse earthy sand with a few large boulders. Resting upon this was a layer of peat (3), from an inch to a foot or eighteen inches in thickness. It contained many fragments of wood, principally birch. From this many wing-cases of beetles have been obtained, amongst them being one of *Geotrupes stercorarius*, as determined by Dr. Purves. Above the peat came two to four inches of sandy clay (4), often crowded with vegetable débris, and

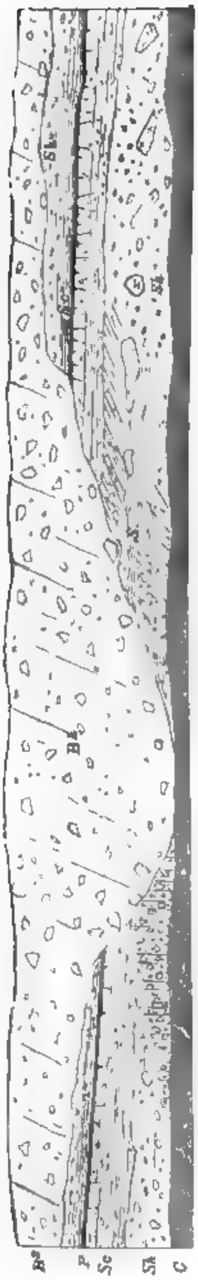


Fig 34. B^1, lower boulder clay; B^2, upper boulder-clay; *Sh*, sand and shingle; *Sc*, silty sand; *P*, peat; *C*, carboniferous strata.

attaining in places a thickness of five or six feet. This was succeeded by a coarse sandy clay, charged with boulders and stones. A mass of normal till, from a few feet to several yards in thickness, formed the uppermost member of the series.[1] Another section taken at the same time from a different part of the quarry is shown in Fig. 34.

At Craiglockhart Hill, about a mile south of Edinburgh, an intercalated bed of sand was exposed during the operations for the erection of the City Poorhouse some years ago. The bed was from one to three feet thick, and Dr. Croll[2] obtained from it a quantity of vegetable remains which were unfortunately in too decayed a state to allow of their specific character being determined. A great many tree-roots were observed in the position in which they had grown. The sand rested upon a mass of till, and was covered by another accumulation of boulder-clay. The roots did not extend upwards into the overlying till, the stones and boulders of which rested directly upon the upper ends of the roots, which were abruptly truncated.

Mr. John Henderson has described the occurrence of a bed of peat, with associated deposits of sand and gravel, that lay between two masses of till at Redhall Quarry, near Edinburgh.[3]

[1] A somewhat fuller description of these deposits is given in my *Prehistoric Europe*, p. 256. The peat-bed has since been removed in cutting back the quarry.

[2] *Climate and Time*, p. 245.

[3] *Trans. Geol. Soc. Edin.* vol. ii. p. 391.

This section has been carefully searched from time to time by Mr. Bennie, who has obtained from the peat the fruits and seeds of upwards of fifty flowering plants, most of which have been identified by Mr. Clement Reid.[1] Associated with these are elytra of beetles and caddis-cases. Among the many plants obtained from this locality are hazel (*Corylus Avellana*), the nuts of which are very abundant; the oak (*Quercus robur*), the alder (*Alnus glutinosa*), and Scots fir (*Pinus sylvestris*). The whole of the plants, Mr. Reid tells us, are still native to the Scottish Lowlands, with the exception of *Galeopsis Tetrahit* (the common hemp-nettle) and *Carum Carui* (caraway), which are not now indigenous to Britain. Recently one of my pupils, Mr. Adamson, succeeded in obtaining the metacarpal of a small ox from the peat. The bone was firmly embedded in the peat and as deeply stained as all the associated fragments of wood.

A bed of clay resting upon, and covered by till, was observed by Mr. R. Craig in a limestone quarry at Overtown, near Beith, Ayrshire. The clay was full of roots and stems of the common hazel, which had evidently grown *in situ* long before the upper till was laid down. Hazel-nuts were plentiful in the clay, which occupied a basin-shaped hollow in the surface of the lower till, about 130 yards long, by 30 yards broad.[2]

At Hillhead, some distance from Overtown, the same observer noticed a similar intercalated deposit of clay full of remains of hazel. The overlying till contained lumps of the fresh-water clay with its characteristic fragments of hazel. From the same bed of boulder-clay, Mr. D. Robertson obtained a fresh-water ostracod.[3]

Mr. Robert Dunlop has described[4] the occurrence of a bed of peat, seventeen inches thick, as occurring between boulder-clays at Burnhead Quarry, about two miles east of

[1] 'Notes on the Geological History of the Recent Flora of Britain,' *Annals of Botany*, vol. ii. No. vi. 1888. The reader will find in this paper a list of all the plants met with in Scottish interglacial beds.

[2] *Trans. Geol. Soc. Glas.* vol. iv. p. 145.

[3] *Op. et loc. cit.* At Orbiston (Lanarkshire) I have noticed a similar fresh-water clay with hazel-nuts. It rested in hollows of the till, and although at the time of my visit I did not see the clay overlapped by till, yet I felt sure from its position that it could not be of postglacial age.

[4] *Trans. Geol. Soc. Glas.* vol. viii. p. 312.

Airdrie. It is crowded with seeds. Most of the plant-remains, according to Mr. Clement Reid,[1] belong to two species—the common mare's-tail (*Hippuris vulgaris*), and the bog-bean (*Menyanthes trifoliata*). Some leaves were identified as those of *Betula nana* (dwarf birch), the occurrence of which, as Mr. Reid remarks, gives a somewhat northern character to the flora.

Mr. Craig likewise notes the occurrence of two beds of till at Roughwood Quarry, Beith. The upper bed rests directly upon the lower, save at one place where 'a thin bed of water-rolled shale lay in the line of division, and in the bottom of the upper bed a species of moss was found.'

The aqueous beds intercalated with the till not infrequently appear to lie in basins or saucer-shaped hollows or depressions. A good example of this was formerly exposed near Neilston, in the cutting of the railway from Crofthead to Kilmarnock.[2] This railway traverses the valley of the Cowdon Burn, and during the progress of the excavations, which were extensive, some exceedingly interesting phenomena came to light. The section (Fig. 35) shows the face of the cutting as seen in 1868. In the woodcut *t* represents the till, of which there are two beds, one at the top and the other at the bottom of the section. Both beds are good typical examples of till, being quite unstratified, and crammed with angular, scratched, and polished stones. The intercalated beds, *c*, consist of silt, clay, mud, sand, and fine gravel, all well bedded, and here and there thin lines and layers of peaty matter occur. The underlying rocks, *r*, are beautifully smoothed and striated. A section (Fig. 36) drawn at right angles to the preceding one, that is, across the line of railway, will show the general relation of these drifts to the valley in which they lie. The intercalated beds are remarkable

[1] *Annals of Botany*, vol. ii. No. vi. 1888.

[2] See papers by the author, *Geol. Mag.* vol. v. p. 393; vol. vi. p. 73. My interpretation of the section, which seemed to me self-obvious, was doubted by Mr. Craig (*Geol. Mag.* vol. v. p. 486), but his re-investigation of the ground seems to have satisfied him that the overlying boulder-clay was really *in situ*. Mr. Bennie, who visited the section several times during the progress of the railway operations, never had any doubt as to the interglacial position of the lacustrine beds, and the same was the opinion of my colleagues on the Geological Survey—MM. A. Geikie, J. Croll, R. L. Jack, and H. M. Skae. I happened to be staying in the neighbourhood at the time, and frequently visited the section while it was being developed by the workmen, and never saw reason to modify the conclusion I had come to after my first careful examination.

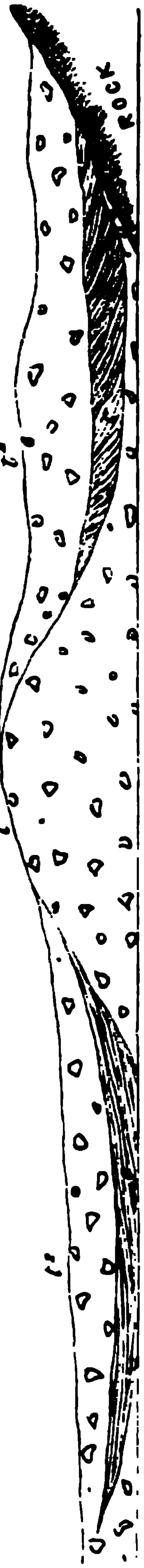


Fig. 35. —Fossiliferous deposits, *c*, in till, *t*: Cowdon Burn Railway Cutting, Neilston, Renfrewshire.

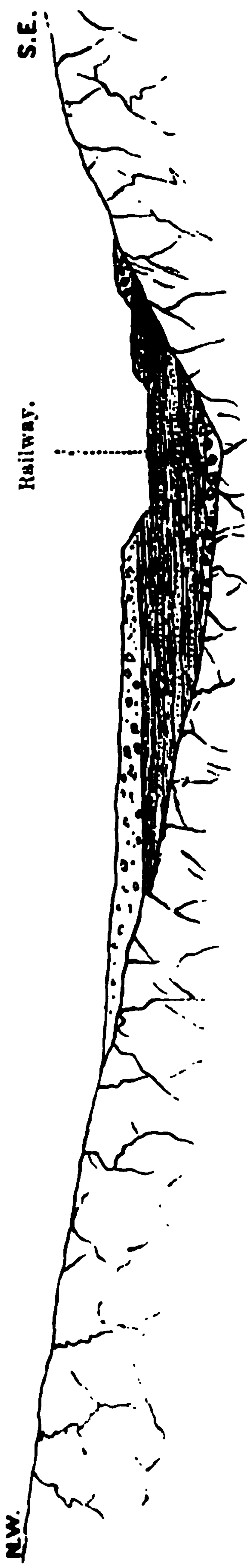


Fig. 36.—Section across the valley of Cowdon Burn, showing fossiliferous deposits resting upon till, and covered by another overlying mass of till.

for having yielded an imperfect skull of the great extinct ox (*Bos primigenius*), and remains of Irish elk or deer and horse, together with layers of peaty matter. From the silt and peat many relics of a varied temperate fauna and flora were obtained by Mr. Mahony,[1] Mr. D. Robertson,[2] and Mr. J. Bennie.[3] Amongst the remains were traces of infusorial life; spiculæ and eggs of fresh-water sponges; jaws of a leech, gemmules of a freshwater polyzoön (*Cristatella mucedo*); six or more species of Coleoptera; caddis-cases, belonging to four or five species; 'water-fleas' (*Daphnia*), which occurred in great abundance; desmids; diatoms; four species of mosses; and the seeds of twenty-eight kinds of flowering plants, including white birch (*Betula alba*), hazel (*Corylus Avellana*), willow (*Salix repens*), Scots fir (*Pinus sylvestris*), &c.

In a gravel and sand-pit near Carham, on the Tweed, I obtained numerous small bones, which Professor Huxley subsequently determined to be those of frogs and water-rats. They lay in a bed of yellow sand and fine gravel, in which a few stones occurred sporadically here and there. Underneath was an irregular mass of rather sandy and loose boulder-clay, full of the usual blunted and glaciated stones. Above the sand-bed came a thickness of twenty or twenty-five feet of a rude pell-mell assemblage of glaciated and rounded stones, with here and there some unpolished angular fragments and large blocks of a siliceous limestone which occurs in place a little farther up the valley. Occasional lenticular patches of fine sand and gravel occurred in the mass, which was faintly stratified in part, the lines of deposition pointing in a direction down the valley. This latter deposit has no connection with the gravels of the present river, the modern river valley having been excavated through the drifts, of which the one I refer to forms a part.

In the mass of the till itself, fossils sometimes, but very rarely, occur. Tusks of the mammoth, reindeer antlers, and fragments of oak and other trees have, from time to time, been discovered in this position. They almost invariably afford marks of having been subjected to the same action as

[1] *Geol. Mag.* vol. vi. p. 390. [2] *Palæontographical Society*, 1874.
[3] *Trans. Geol. Soc. Glas.* 1891.

the stones and boulders by which they are surrounded; that is to say, they are rubbed, ground, striated, and smoothed. Sea-shells, broken, crushed, and striated, also occur under similar circumstances in certain deposits of till which fall to be described farther on.

Before leaving the non-marine intercalated beds of the till, I would remind the reader of what has already been said with regard to the remarkable 'striated pavements.' (See pp. 15, 74). It is quite possible that these pavements may really have the same meaning as the intercalated fossiliferous beds just described. They may represent long pauses in the accumulation of till.

CHAPTER VIII.

BEDS SUBJACENT TO AND INTERCALATED WITH THE SCOTTISH TILL—*continued.*

Beds below and in the till indicate pauses in the formation of that deposit—How the aqueous beds have been preserved—Their crumpled and denuded appearance—Their distribution—Character of the valleys in which they occur—The present stream-courses, partly of preglacial, interglacial, and postglacial age—Old course of the River Avon, Lanarkshire—Preglacial courses of the Calder Water and Tillon Burn—Buried river-channel between Kilsyth and Grangemouth.

WE may now proceed to the explanation of the facts adduced in the last chapter. The reader has already seen that the till itself is a truly glacial deposit, due to the grinding action over the surface of the country of an immense *mer de glace.* But no one will doubt that its intercalated and subjacent beds of silt, sand, and gravel have had a very different origin. They occur in such layers as could only have been spread out by the action of running water. Evidently, then, these strata are a very different kind of deposit from the till that encloses them, and it is equally self-evident that at the period of their formation the production of till must for a time have ceased, at least in those particular places where the stratified beds occur. And seeing that these intercalated beds are not confined to any one district, but are found in every part of the country where they have been searched for, it is reasonable to conclude that there were times when the great ice-fields that covered the country receded so far at least as to uncover the lowland tracts and valleys, and permit the accumulation in those regions of water-arranged clay, sand, and gravel. Nor does it seem less reasonable also to conclude that after such a recession the ice again advanced and covered up the aqueous strata with thick deposits of stony clay. But here a difficulty will occur to the reader which it may be well to notice. How, it may be

asked, could soft beds of sand, silt, and gravel escape being ploughed out by the ice-streams which are said to have deposited the overlying stony clay?

It has already been pointed out that the existence of the till itself is a difficulty of the same kind; and I have endeavoured to show that this deposit bore the same relation to the ice-sheet that river-detritus does to a river. There can be no doubt that in many places over which the ice-sheet passed till could not possibly accumulate, just as in the bed of a stream there are bare rocky slopes exposed to the full sweep of the water where detritus is not permitted to gather. It is no less certain that after till had been piled up in some places it was again and again ploughed out, and redistributed below the ice-sheet. Now we find that the intercalated beds of sand and gravel give unequivocal proof of having been subjected to great pressure. They are twisted, bent, crumpled, and confused, often in the wildest manner.[1] Layers of clay, sand, and gravel, which were probably deposited in a nearly horizontal plane, are puckered into folds and sharply curved into vertical positions. I have seen whole beds of sand and clay which had all the appearance of having been pushed forward bodily for some distance, the bedding assuming the most fantastic appearance.[2] (See Figs. 26, 28, 29, 30, 31.)

But the intercalated beds have not been crumpled only; they are everywhere cut through by the overlying till, and large portions have been carried away. Indeed, when we compare the bulk of these beds with that of the till, we must at once allow that they form but a small fraction of the superficial deposits. Owing to the erosive power of the old glaciers, comparatively little of the intercalated sand, &c., has been spared; but enough is left to assure us of the former

[1] In certain regions, however, particularly as we approach the limits reached by the old ice-sheets, the stratified beds lying in and below the till or boulder-clay are often comparatively undisturbed over considerable areas. This is specially the case in England, the Continent, and North America, as will be pointed out in the sequel. The remarks in the present chapter have special reference to the preservation of intercalated deposits in a highly glaciated region.

[2] For a graphic account of contorted intercalated beds, the reader may refer to my brother's description of the Chapelhall deposits (mentioned *ante*, p. 99). He tells us that so great had been the pressure of the ice that the till appeared as if it had been injected between and among the layers of clay and sand. (*Trans. Geol. Soc. Glas.* vol. i. part 2.)

importance of the intercalated beds. The geological valı of a deposit has not usually been measured by its bulk.

In exposed positions, such as hill-tops and hill-slopes, tl till never contains intercalated beds ; nor do these occur, sa as interrupted and fragmentary patches, in places that appe to have been open to the full sweep of the ice-currents. is usually in positions sheltered in great measure from tl pressure and grinding of the glaciers that the stratified be of the till have been best preserved. But what, it may asked, is meant by a position sheltered from the grind of t ice? Do not these sand and gravel beds occur exclusive in the valleys, and is it not just in such positions where tl grinding action of the old glaciers was most powerful? the ice-sheet covered the whole country, in what possible po tion could the sand and gravel beds be comparatively secur Let me try to make this plain. In Scotland, as in oth countries, the large rivers flow in broad open valleys, and a fed by lateral tributaries which issue from narrower and mo confined valleys and ravines. The River Clyde, for exampl which flows towards the north-west in a valley that gradual expands to a broad open strath, as it approaches its estuar is joined from north and south by numerous streams, mar of which run in deep narrow ravines, until they are just c the point of mingling their waters with the river. This a pearance is very well seen in the neighbourhood of Hamilto The Avon there winds through a deep cool ravine for sever miles before it enters the Clyde, and the same is the ca with the little tributaries of the Avon itself. The Cald from the north-east also makes its way towards the Clyde a romantic glen, whose precipitous walls, like those of t Avon, are hung with greenery. Now during the glacial peri the ice-sheet, which followed the lines of the principal valley must frequently have crossed the lateral and tributary valle nearly at right angles. In the main valleys the glacier wou exert its full influence, but, as my brother has pointed o it would not be able to do so in the narrow lateral valleys a ravines ; the ice and till would merely topple into the gle referred to, and gradually choke them up, and the main ma of the glacier would then pass on over the whole. Here t analogy of running water again will help us. In a strea

course we see how the detritus accumulates in deep holes and pools, at the bottom of which the water is often well-nigh still, while a current is sweeping across at the surface.

In such narrow glens, then, any silt, sand, or gravel that had gathered during the temporary absence of the ice-sheet would not be so likely to be ploughed out when the ice returned, as the similar materials which had accumulated in those broader and more open valleys where the ice would have full freedom to move and exert its erosive power.

But it may be objected that it is precisely in the narrower ravines where at the present day we meet with no drift whatever, where in fact the streams flow between bare walls of rock; while, on the contrary, the broader and more open valleys show considerable depths of sand, silt, gravel, and stony clay. To this objection it may be answered that the narrow ravines in which so many of our streams flow have been formed almost without exception since the close of the glacial period. The ravines are in most cases new cuts excavated by the streams after the confluent glaciers had finally vanished.

How this has happened will readily appear when we remember that the work performed by the old glaciers was twofold. In many cases the massive ice-streams deepened the valleys that already existed—in certain regions grinding out great hollows, to the nature and origin of which reference will be made in a subsequent chapter. But after having deepened valleys and widened glens, they very frequently buried these again more or less completely under piles of clay, sand, and boulders. Some lowland valleys indeed they completely obliterated, so that when the ice finally melted away, and left the land once more exposed to the light of day, the streams and rivers could no longer flow in their old courses, but were compelled to form for themselves new channels.

It is quite true that, speaking generally, the present drainage-system is very much the same as that which obtained before the advent of the glacial period; nevertheless the course followed by each river and stream seldom agrees precisely with that along which the waters made their way in preglacial times. Sometimes the streams flow throughout nearly their entire length in new channels which have been

cut in rock since glacial times, the older courses being still choked up and concealed under the clay and stones that were shot into them by the old glaciers. More frequently, however, the present river-courses are partly new, partly old. When, after the ice had disappeared, water again began to make its way down the slopes of the land to the sea, it is self-evident that the direction of the streams would be determined by the configuration of the ground. But this, as we have seen, would not exactly agree with that of preglacial times. Many of the valleys had been levelled up, and in not a few cases long hills and mounds of glacial detritus appeared where deep dells had formerly existed. The chief features of the country, however, remained; the broad valleys and straths, although clothed with superficial deposits, yet again received the tribute of the lateral streams, and formed the highways of the principal rivers. But the lateral feeders of these rivers, following the new slopes of the ground, have not always been directed into their old channels. Sometimes, indeed, they wander for miles away from these, and join the main stream either far above or far below where they formerly debouched. Even when, after cutting down through the glacial deposits, they have happened to regain their old channels, they usually leave these again and again as they journey on, plunging ever and anon into deep rocky gorges, which, as I have said, have been chiselled out by them since the close of the glacial period.

To the wanderer along the course of some of the lowland streams, as, for example, that of the Esk near Edinburgh, nothing can be more striking than the sudden and complete change of scenery that ensues upon the passage of a stream from its new into its old channel. In the former the water frets and fumes between lofty walls of rock, which, seen from below, appear to rise almost vertically from the river's bed. In such a deep narrow gorge the stream may continue to flow for miles, when of a sudden the precipitous cliffs abruptly terminate, and the water then escapes into a broad vale with long sloping banks of stony clay, sand, and gravel. After winding about in this open glade for, it may be, several miles, the stream not infrequently leaves again as suddenly as it entered, and dashes once more into another dell, whose steep

walls of rock shoot up and overhang the water as before. The broader and more open portion of the valley, where the sloping banks are formed of glacial débris, is of course that part of the old preglacial channel which the present stream has re-excavated; while, as already indicated, the narrow and rocky gorges are entirely new cuts made by the stream during the ages that have elapsed since the glacial period.

In many cases the present streams seldom continue in their old channels for any distance. We often find them cutting across these nearly at right angles, and in this way fine sections of the old buried river-channels with their contents frequently appear in the rocky glens of the Lowlands, to some of which I shall refer presently. A glance at the

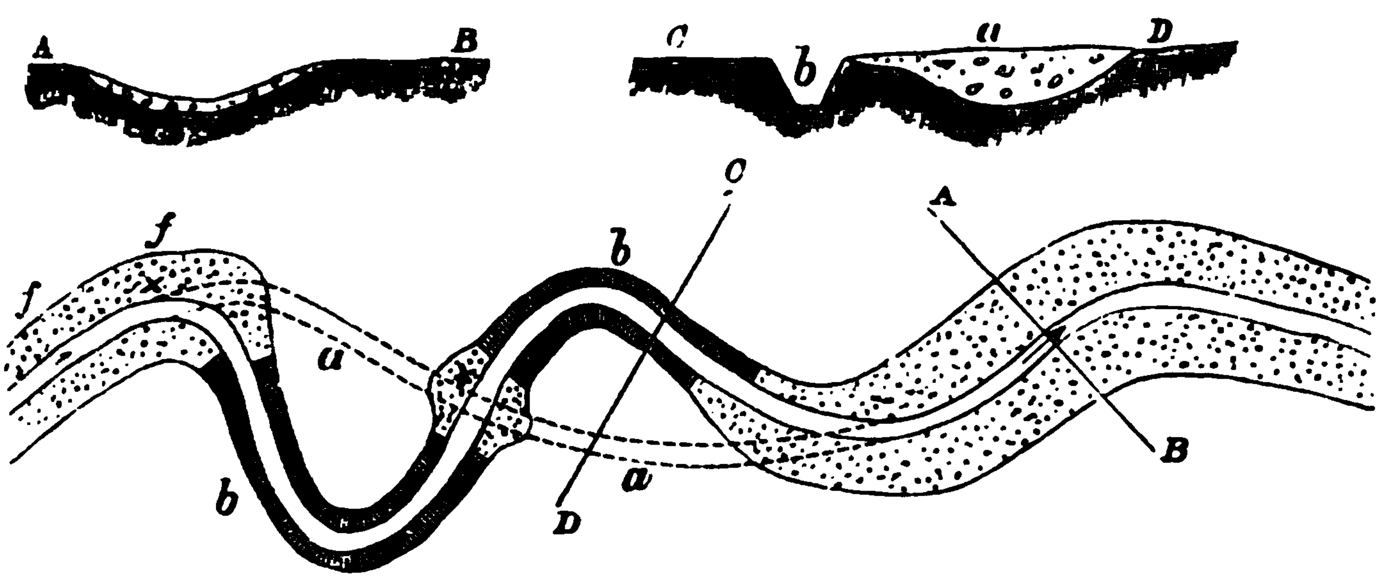


Fig. 37.—Diagram to show preglacial and postglacial river-course. *a a*, buried course; *b b*, postglacial channel; *f f* and dotted parts show re-excavated channel. Sections above indicate character of valley along the lines *A B* and *C D*.

woodcut (Fig. 37), which is a diagrammatic ground-plan intended to illustrate the phenomena just described, will show how it comes to pass that a postglacial channel may often cut a preglacial course, and yet the present stream coincide in direction with that of preglacial times. The buried course is represented at *a a*, and the new channel at *b b*; the thin line, on either side indicating the tops of the cliffs, *b b*, and sloping banks, *f f*. From *f* to *f* it will be observed that the present channel coincides exactly with the old course, while at × × the latter is cut across nearly at right angles by the former.

In most cases the preglacial channels prove to be wider and sometimes deeper than the new cuts; consequently when

a stream, after flowing for some distance in a postglacial course, suddenly enters a preglacial channel, the softer character of the materials it has to excavate enables it to clear out a wider hollow than it has carved in the solid rock of its postglacial course. A section across the valley at *A B*, compared with one drawn from *C* to *D*, shows the relative appearance of the old and new cuts. It will be noticed that not only are the old channels wider and sometimes deeper than the new—facts which indicate, of course, a greater age—but also that their sides are less precipitous. This latter appearance points to the long-continued action of springs and frost, which, by undermining, splitting up, and detaching the rocks upon a cliff, have a tendency to reduce all such steep river-walls to sloping banks; but the gently-inclined slopes of many preglacial river-courses doubtless owe much of their character to the grinding action of the glaciers during the Ice Age. Not a few old river-courses, however, can be shown to be as steep and precipitous as any which have been formed since glacial times.

I do not believe it was necessary, however, for the preservation of intercalated deposits that they should always have occupied a hollow or depression sheltered from the full sweep of the ice-flow. The great thickness attained by the till in broad open lowland districts shows that over such areas there was a tendency for the till to accumulate, probably owing to a diminished rate of ice-flow. We see analogous phenomena in the case of a river, which, as the fall of the ground lessens, spreads itself out, becomes sluggish, and begins to deposit sediment in its course. Now, wherever the flow of the ice-sheet slackened there would necessarily be less erosive action, and therefore a greater chance of preglacial, intraglacial, and interglacial beds being preserved. For the same reason we ought to find, as we approach the limits reached by the confluent glaciers, that subjacent and intercalated deposits have suffered less erosion. When we come to consider the superficial accumulations of England, the Continent, and America we shall meet with some striking illustrations of the phenomena in question.

To the appearance presented by the deposits that fill up the buried river-channels I must now direct attention. At

page 92 I have given the details of a boring made near Larkhall, for the purpose of testing the position of the underlying coal-seams. This boring and another near the same place pierce a great thickness of detrital materials which I have ascertained occupy a former course of the Avon—the present river flowing for a considerable distance in an entirely new channel excavated since the glacial period. Thė following figure gives a diagrammatic view of the choked-up channel as it has been ascertained by borings. A section of the old channel, where it is cut by the Avon, is seen on the banks of the river near Fairholm House, Larkhall; but owing to the incoherent nature of the silt and sand, these beds have slid forwards with the overlying clays and thrown everything into confusion. It will be remembered that the

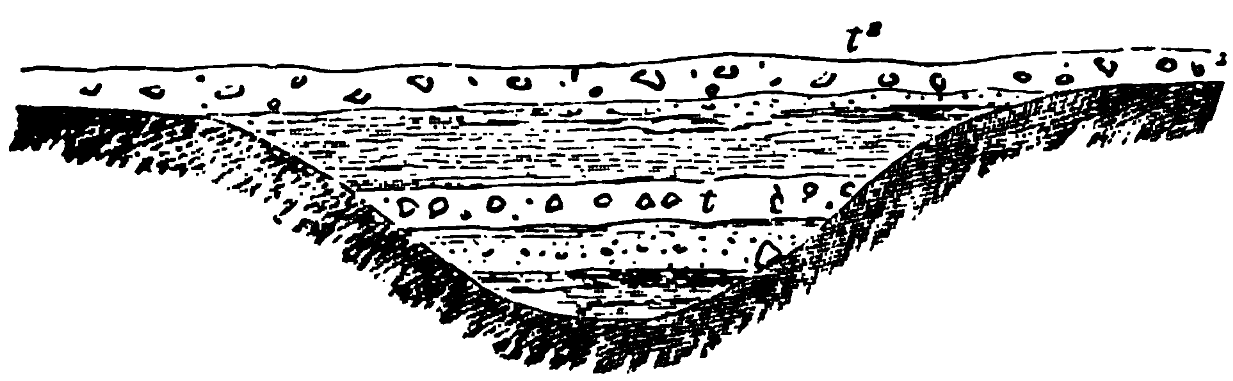


Fig. 38.—Diagrammatic section across preglacial course of the River Avon, Larkhall, Lanarkshire. *t*, lower till; *t*², upper till.

borings prove the existence of two masses of till, with intervening and underlying beds of silt, mud, sand, and gravel. The lower of these two deposits of till indicates the prolonged action of glacier ice; yet the beds below retain a considerable thickness, notwithstanding their incoherent character. At this particular place, however, the ice-sheet crossed the gorge in which they lie at an angle, and hence they must needs have escaped the powerful erosion to which they would have been subjected had the path of the ice coincided with the trend of the ravine. The presence of 40 ft. of silt, sand, and gravel above the till indicates a period of lessened cold when the ice-sheet disappeared from this region and permitted the formation of such deposits. But after a time it would seem that the ice-sheet again overspread the country, doubtless sweeping out the silt, sand, and gravel from exposed positions,

but sparing them in the narrow glens and gullies that intersected its path.

In the Scottish coal-fields such old stream-courses[1] as I now describe are of common occurrence, and are locally known to the miners as 'clay dykes' and 'sand dykes,' according to the prevailing character of the material that fills them. The coal is often worked quite close to the side of the buried ravine; after which, if the nature of the dyke will allow it, a mine is driven through the clay and sand, until the opposite face of the old glen is reached and the coal-seam found again. Sometimes, however, the dyke is charged with soft mud and running sand, and then it becomes impossible to mine, and a new pit must be sunk on the farther side of the channel to get out the coal. Many accidents have happened from the irruption of sand and mud into the pit-workings, when coal has been taken out too close to a dyke.

A very good example of such a dyke, or buried stream-course, was exposed in the cutting made for the railway between Edinburgh and Holytown, quite close to the little village of Cleland, Lanarkshire. The cutting intersected the channel at right angles to its course, and thus a beautiful section of the old ravine, and the materials that choke it up, was obtained.[2] But the face of the cutting is now so 'dressed,' that the precise succession of the drift-beds cannot be deciphered. There cannot be a doubt, however, that a thick mass of till occupies the highest position, with beds of gravel and sand coming in below. The same old ravine is intersected by the Calder Water a little to the west of Wishaw House, where, however, the trees and brushwood somewhat obscure it.

It is remarkable that in the same neighbourhood there is another buried stream-course, which runs for a short distance parallel to the last-mentioned one, and is in like manner cut

[1] For notices of some of these see Mr. Milne Home's *Memoir on the Mid-Lothian Coal-Field*; A. Geikie 'On the Glacial Drift of Scotland,' *Trans. Geol. Soc. Glas.* vol. i. pt. 2; *Quart. Jour. Geol. Soc.* vol. v. p. 20; *Mem. Geol. Surv.* (34 *Scotland*), p. 50; *Ibid.* (23 *Scotland*), p. 42; *Geological Magazine*, vol. ii. p. 38. There are many 'dry valleys' in Scotland which evidently date back to preglacial times: they usually contain drift of some kind, but sometimes they do not. See a notice of some of these in *Mem. Geol. Surv.* (33 *Scotland*), p. 63.

[2] See a paper by Mr. R. Dick, *Trans. Geol. Soc. Edin.* vol. i. p. 345; Mr. Dick seems to have thought that this buried channel and the one referred to in the next paragraph were one and the same.

across by the present course of the Calder. It is well exposed on the banks of this stream a little below Coltness bridge, upon the side of the road leading from Wishaw. Both buried channels are filled with similar materials, chiefly sand with a little gravel—the whole being covered with till. The coal-workings, which are very extensive in the district, enabled me, while carrying on the Geological Survey, to trace out all the windings of these remarkable sand-troughs; and by connecting the information thus obtained with what I was able to gather from natural sections, it became evident that considerable changes had taken place in the drainage-system of the neighbourhood since glacial times. The Tillon Burn, which is now a tributary of the Calder, was formerly an independent stream; while the Calder Water has forsaken its old channel, and at present flows for some distance in an entirely new course, after which it breaks into and continues along the preglacial or interglacial course of the Tillon Burn.[1]

Fig. 39.—Section across Carboniferous strata, showing preglacial stream-courses (scale 6 inches to 1 mile; horizontal and vertical scale the same); *t* till; *c* preglacial course of Calder Water; **T** preglacial course of Tillon Burn; *f* dislocations, or faults, in coal-bearing strata.

I shall refer to only another example of preglacial watercourses.[2] This buried river-course has been traced from Kilsyth to Grangemouth, on the Forth, where it enters that estuary at the great depth of 260 ft. below the present sea-level. No trace or indication of the buried river-channel shows at the surface of the ground, and its existence would probably never have been discovered had it not been for the numerous borings and pits which have pierced it, for it cuts right through the coal-strata of that district. The nature of the deposits

[1] See Geol. Survey Map of Scotland, Sheet 23.
[2] This 'channel' is described by Dr. Croll in *Trans. Geol. Soc. Edin.* vol. i. p. 330. See *postea*, p. 125, *footnote*.

that fill up the old river-ravine is shown in the following section :—[1]

BORING NEAR TOWNCROFT FARM, GRANGEMOUTH.

		Ft.
Upper Series.	Surface sand	6
	Blue mud	3
	Shell bed	1
	Gravel	2
	Blue mud	8
	Gravel	3
	Blue muddy sand	15
	Red clay	49
Lower Series.	Blue till and stones	20
	Sand	20
	Hard blue till and stones	24
	Sand	2
	Hard blue till and stones	40
	Sand	7
	Hard blue till	24
		224

We shall return to a consideration of these old preglacial river-courses when we come to treat of the superficial deposits of England; for there are certain inferences to be drawn from them which the reader will better appreciate after he has had an opportunity of examining the evidence furnished by the English deposits. At present our chief study is to ascertain if we can the origin of the deposits which choke up the old channels, but we shall have something more to say about the channels themselves when we are discussing the question of the preglacial condition of Britain.

[1] See J. Bennie's 'Surface Geology of the District around Glasgow,' *Trans. Geol. Soc. Glas.* vol. iii. part. i.

CHAPTER IX.

BEDS SUBJACENT TO AND INTERCALATED WITH THE SCOTTISH TILL—*continued.*

Stratified deposits passed through in borings —Probably in most cases of fresh-water origin—Old lake at Neidpath, Peebles—Lakes of interglacial periods —Borings near New Kilpatrick—Preglacial valley of the river Kelvin—Origin of the deposits occupying that buried river-course—Valley between Johnstone and Dalry—Flat lands between Kilpatrick Hills and Paisley—Condition of the country in preglacial times—Leven Valley glacier—Ancient glacial lake—Succession of events during recurrent cold and warm periods.

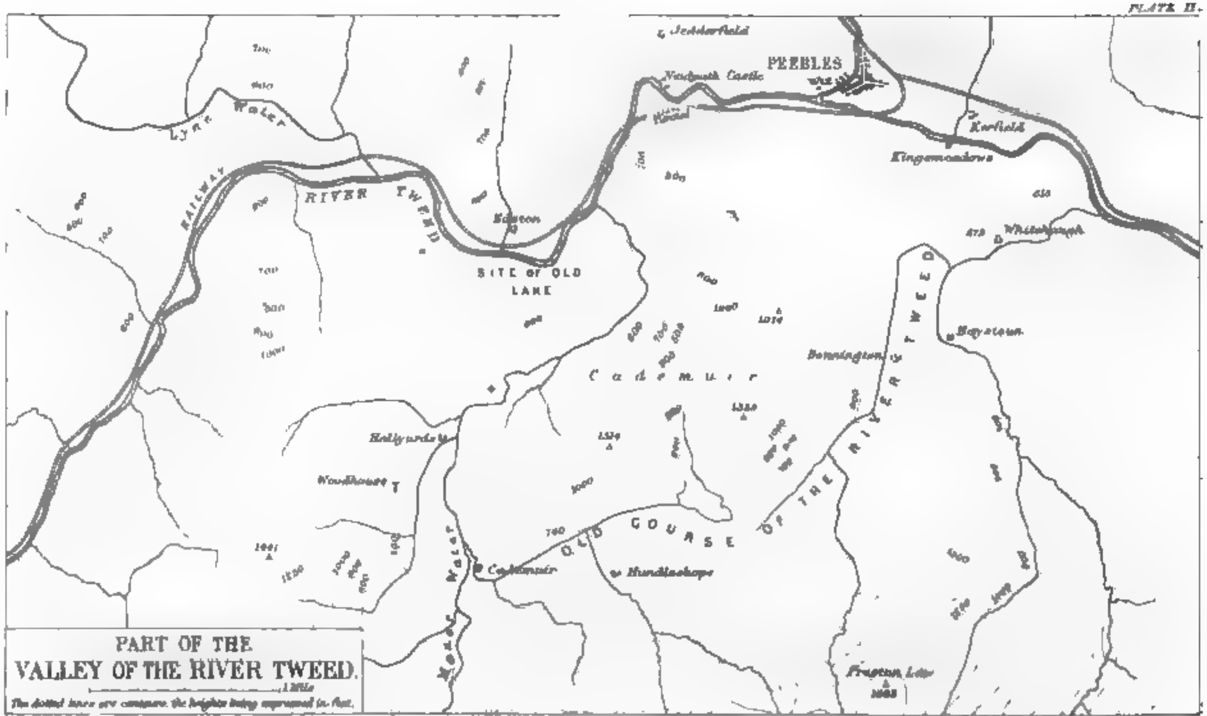
IT will be observed that while the hollows [1] in which these deposits occur have been described as old river-courses, yet nothing has been said as to the origin of the deposits themselves. Of the nature of the overlying till which is seen at the surface in some of the examples cited there can be no doubt; but it may be objected that since we do not always see the intercalated and subjacent stony clays, we cannot be sure as to their character. Might not they be something else than glacial deposits? To this it may be answered that we know of no stony clay in Scotland which is not of glacial origin. If the succession of strata disclosed by artificial borings were altogether peculiar and abnormal, we might have good reason for disregarding them; at all events, we could hardly be justified in drawing conclusions from them. But such successions are neither peculiar nor

[1] Similar preglacial river-courses are known to occur in other countries. An excellent example has been traced out in the underground workings of the Durham coal-fields, by Messrs. Nicholas Wood and E. F. Boyd (*British Association Reports* for 1863, p. 89; *Geologist*, 1863, p. 384). The buried river-courses of North America are also familiar instances. Professor Hitchcock has described these as 'antediluvian river-beds;' that is to say, beds of rivers that existed before the glacial period in North America. Logs and fragments of wood are often got at great depths in the buried gorges ('Illustrations of Surface Geology,' &c., *Smithsonian Contributions*). Professor Newberry and others have more recently given interesting accounts of the like phenomena. See *Geol. Surv. of Ohio*, vol. ii. chap. xxx.

abnormal; on the contrary, similar sections occur at the surface which answer precisely in character to the accumulations passed through by the boring-rods. In the open-air sections the intercalated stony clays are true till, and the stony clays in the deep bore-holes must be till, or at all events, deposits having a glacial origin.

With regard to the aqueous strata which are associated with the stony clays, the almost total absence of fossils makes it in many cases difficult to decide whether they are of fresh-water or marine origin. In some cases, at low levels, it is not unlikely that they are partly one, partly the other. It must be admitted, however, that the absence of organic remains tells more against a marine than a fresh-water origin for the mud, sand, and silt that fill up the buried channels and hollows. It is unfortunate that a greater number of these should not have been exposed to the light of day; nevertheless, enough perhaps are actually exhibited to enable us to form a correct idea of those which are revealed to us by borings and pit-workings. The opinion to which I incline is that the aqueous beds now filling up the old hollows and depressions of the land are in large measure of fresh-water origin. But if this be so, it seems certain that they cannot all have been laid down in the old ravines and valleys under conditions like those now obtaining in similar watercourses and depressions. No geologist would admit that the great depths of fine sand, silt, and mud, which occupy the buried hollows, could possibly have been deposited by such streams as now flow in similar places.

In many cases the deep aqueous drifts, as exposed in open section, have quite a lacustrine character. This was well seen in the section at Neidpath Tunnel, briefly described on page 96. The stratified beds in that locality appear to have been once very extensive—traces of the same deposits having been found in and below the till for some distance up the valley of the Tweed. At Neidpath there was a depth of from 40 to 50 ft. exposed, and the bottom was not seen. The beds partook of fluviatile and lacustrine characters (chiefly the latter), and appear to have been deposited in a lake-like expansion of the Tweed, at a time when that river flowed, not by its present course, but round by the back of



PART OF THE
VALLEY OF THE RIVER TWEED.

1 Mile

The dotted lines are contours, the heights being expressed in feet.

To face page 112

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Cademuir Hill. The accompanying sketch-map (Plate II.) will serve to render this intelligible.

It will be seen that from Cademuir Farm to Bonnington there extends a broad flat hollow, the bottom of which at its highest level is only some 100 ft. or so above the bed of the Tweed at Neidpath. Were the narrow glen at this latter place to be filled up, the Tweed would be dammed back, a lake would be formed, and thereafter both the Tweed and its affluent, the Manor Water, would flow round by the Cademuir hollow. That such actually was the course of one or both these streams at a comparatively recent geological date is proved by the fact that the Cademuir hollow is paved with river-gravel, which could have come from no other source.

An examination of the present and the former course of the Tweed and the surrounding drift phenomena led me to conclude that the 'gutta-percha clays' of the Neidpath section were deposited at a time anterior to the cutting-out of the Neidpath glen by the river; that, in short, the Tweed before the advent of the last general *mer de glace* flowed by the Cademuir hollow; and that Neidpath glen has been to some extent at least hollowed out since the final disappearance of the ice-sheet. The alterations of surface brought about by the massive glacier that cut through the gutta-percha clays and deposited the tumultuous mass of till above them, and the modifications of level induced by denudation in later glacial times, eventually compelled the Tweed to leave its old course and take the more direct route by Neidpath.

The occurrence of preglacial and intraglacial lacustrine beds in the river-valleys is only what one might have expected. Whenever the ice-sheet retired an irregular surface of glacial drift would be exposed, in the hollows and depressions of which lakes and pools would gather. Nay, in some cases the mouths of small lateral valleys would be closed up with detritus, and thus, streams being dammed back, sheets of water would be formed in which fine sediments would accumulate. In like manner the glaciers themselves would not infrequently become barriers to the drainage of small lateral valleys, and in this way true glacial lakes would come into existence. Hence we need not

be surprised at the frequent appearance of old lacustrine beds in the valleys. It would be much more surprising if they did not occur.

It is well known that in the valley of the Kelvin, near New Kilpatrick, a number of borings prove the existence in that district of a very great depth of superficial deposits. Two examples[1] of these borings may be given; they are as follows:—

	Ft.	Ins.
Sandy clay	5	0
Brown clay and stones [till]	17	0
Mud	15	0
Sandy mud	31	0
Sand and gravel	28	0
Sandy clay and gravel	17	0
Sand	5	0
Mud	6	0
Sand	14	0
Gravel	30	0
Brown sandy clay and stones [till]	30	0
Hard red gravel	4	6
Light mud and sand	1	8
Light clay and stones	6	6
Light clay and whin block	26	0
Fine sandy mud	36	0
Brown clay, gravel, and stones	14	4
Dark clay and stones [till]	68	0
	355	0

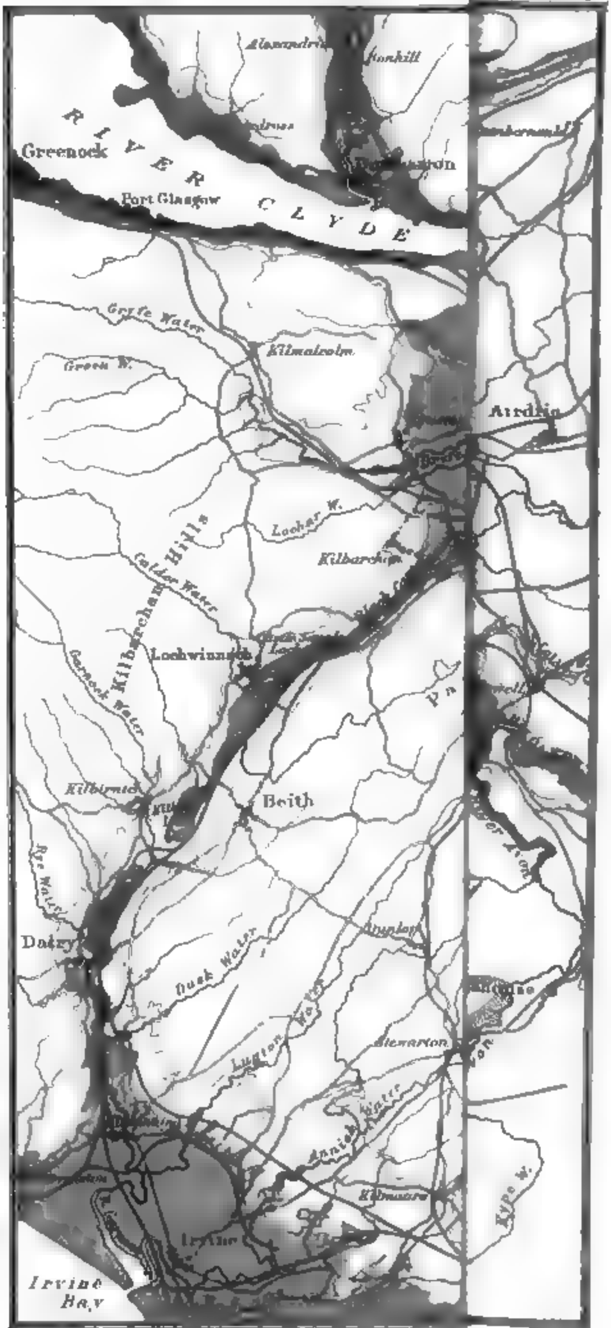
Another boring in the same neighbourhood gave:—

	Ft.	Ins.
Soil	1	6
Muddy sand and stones	4	0
Soft mud	4	6
Sand and gravel	45	0
Sandy mud and stones	20	6
Sandy gravel and mud	52	4
Brown clay and stones [till]	25	0
Sand and gravel	6	0
Brown sandy clay and stones [till]	12	0
Sand	2	0
Brown sandy clay and stones [till]	4	0
Mud and sand	15	9
Sand and blue clay and stones	7	9
	200	4

Dr. Croll has suggested that these deep drifts may occupy a preglacial bed of the Kelvin. If so, then this ancient buried channel must enter the Clyde at a depth of more than 200 ft. below the present sea-level. There is nothing

[1] For these and other borings see Mr. Bennie's paper, *Trans. Geol. Soc. Glas.* vol. iii. p. 133.

PLATE III.



To face page 161

abnormal in this. It has already been mentioned that an old buried river-channel enters the Forth near Grangemouth at a depth of at least 260 ft. below the sea; from which we must infer that at some period anterior to the filling-up of that channel the land stood at least 260 ft. higher than the present datum-line. In a subsequent page I shall have occasion to point out that the great sea-lochs of the western coasts are merely submerged land-valleys. Indeed, if we could but remove the superficial deposits from the surface of the Lowlands there can be no doubt that the sea would also reach a long way into the heart of these districts, penetrating sometimes for many miles by such valleys as that of the Clyde, the Ayr, the Stinchar, the Tweed, and other rivers.

Of all these valleys that of the Clyde has yielded the greatest depth of superficial accumulations—these deposits reaching, in at least one place, the excessive thickness of 357 ft. No one can glance over the borer's sections given above without feeling assured that, whether or not the gravels, sands, and muds occupy a buried river-valley, they at least could not have accumulated underneath a river—they are either estuarine, lacustrine, or marine, or finally, they may partake of a mixed character, and be partly of fresh-water and partly of marine origin. Their general resemblance to similar deposits exposed in other districts would incline me to consider them as for the most part of lacustrine origin, and an examination of the physical features of the district certainly tends to support this suggestion. As the question is an interesting one, it may be well to consider it in detail.[1]

Those who have travelled from Glasgow by Paisley and Johnstone into Ayrshire will remember that the railway in its course towards the latter place skirts the base of some rising ground which towards the south slopes up to form what we may call, for want of a general name, the Paisley Hills. (See Plate III.) From the base of these hills a wide

[1] Mr. D. Bell has advanced an explanation of these intercalated beds somewhat similar to that given in the text. He speculates on the damming-up of the Clyde at Bowling, the consequent formation of a lake, and the egress of the waters by Lochwinnoch and Dalry (*Trans. Geol. Soc. Glas.* vol. iv. p. 66). Mr. Bell's views and mine were arrived at independently; but since his have the priority of publication, he is justly entitled to claim the 'copyright' of the glacial lake described in the text.

stretch of flat or gently-undulating country extends northwards to the foot of the Kilpatrick Hills, and westwards until it abuts upon the lower slopes of the Kilbarchan Hills. On north, south, and west, then, this plain is encircled by a screen of hilly ground. The screen, however, is breached in two places: at Bowling by the Clyde, and at Johnstone by the Black Cart Water. From Johnstone the railway runs up the valley of this water, passing Castle Semple Loch, Barr Loch (now drained), and Kilbirnie Loch, beyond which it follows the same hollow through the hills to the low grounds south of Dalry. The surface of Kilbirnie Loch is very nearly on the same level as that of Castle Semple Loch, but there is a sluggish flow of water from the former to the latter. The head of Kilbirnie Loch, then, we may take as the watershed between the Black Cart Water and the streams that drain along the same hollow towards the south-west. But anyone who examines the ground will have no difficulty in concluding that this long hollow has not been excavated by the streams that now flow in different directions along its bottom. They are quite inadequate. The whole appearance of the valley suggests strongly the idea of an old watercourse that once drained along its whole extent from the north-east. That is to say that at some former period a river flowed from the valley of the Clyde across what is now the watershed of the Black Cart Water, and so on south-west into Ayrshire. This no doubt does at first sight seem an impossibility, but that it actually must have happened I shall now try to show.

Let me ask my reader to carry his mind back to the preglacial period—to that far-distant past before ice and snow filled the valleys, and ere yet any accumulation of glacial deposits covered the surface of the country. In those days the Clyde and its affluents certainly flowed at a considerably lower level than they do now. Could we clear away all the superficial deposits that rest in the basin of the Clyde between Glasgow and the sea, we should find, not, as at present, the broad undulating plain that stretches from the base of the Kilpatrick Hills to the heights behind Paisley, but a deep valley dotted with rocky knolls and ridges. We should find also that at least one deep lateral valley, carrying the

drainage of the Campsie and Kilpatrick Hills, entered that of the Clyde from the north-east. The bed of the preglacial Clyde at or near Bowling must lie buried at a depth of more than two hundred feet below the level of the sea. Even at Glasgow the old channel of the river is not less than eighty feet under the same datum-line.[1] Now when the river was flowing at these levels it need hardly be said that the land must have stood relatively higher than it does now; at all events it is certain that our shores extended much farther out to sea.

Let us, then, conceive that while the Clyde valley is in the state I have described, glacial conditions of climate supervene, that snow and ice begin to thicken in the mountain-valleys, and great glaciers to creep out and deploy upon the low grounds. One immense stream of ice fills the mountain-valley now occupied by Loch Lomond, and flowing onwards through the vale of the Leven, advances across the bed of the Clyde until it abuts upon the opposite slopes of the Kilbarchan Hills. This invasion results of course in damming back the Clyde, and a lake accumulates over the low grounds which are encircled by the Kilpatrick, Kilbarchan, and Paisley Hills. But as the Clyde continues to flow and the surface of the lake to rise, the water must eventually find a channel of escape. Now supposing the valley of the Black Cart Water to have existed at this time, it is evident that as the lake rose it would penetrate this valley until it reached the watershed, over which a river would pour south-westward into Ayrshire. It is highly probable, however, that the great hollow now occupied by Kilbirnie and Castle Semple Lochs and the Black Cart was not so strongly pronounced in preglacial times. Be this, however, as it may, it is evident that the old Clyde, swollen in summer-time by melting ice and snow, must have swept through the notch or breach[2] in the

[1] In a series of borings made for the Clyde Trustees at Mavisbank Quay the rock was attained at 70·48 ft., 77·60 ft., and 80·23 ft. below high-water mark in three bores respectively. At Stobcross, on the opposite bank of the river, the borings, at a distance of two or three hundred feet from the water, reached the rock at a nearly similar depth from the same datum-line. But when the borings were continued at the distance of a few hundred feet farther from the river, the rock-head appeared at a less depth from the surface. The superficial deposits were thus shown to thin off towards the north, but they did so in a very irregular manner.

[2] The reader will, perhaps, understand my meaning better, if I merely state

hills with great force, and this condition of things continuing for a long period, the hollow along which the water flowed would be widened and deepened. But before the river had commenced to widen and deepen this secondary course, the lake from which it flowed would cover a large tract of country and stretch along the base of the Kilpatrick Hills as far at least as Kilsyth. In this manner the old lateral valley mentioned above as being probably the preglacial channel of the Kelvin would be completely submerged, and so also would be the bed of the Clyde up to and beyond Glasgow.

The area covered by the lake would then necessarily become an area of deposition. Gravel, sand, mud, and silt would accumulate upon the bottom, the finer sediments settling down in the deeper parts, and thus all the drowned river ravines would have a tendency to silt up. The process would be a gradual one, and sometimes it might even be interrupted by some local recession of the Leven glacier, which would lower the surface of the glacial lake and allow the streams to re-excavate a portion of their beds. But these and other obvious considerations I need not stop to point out.

Let us now further conceive that the cold continues to increase, that the snow and ice grow in depth and breadth until even the Kilpatrick and Campsie Hills are overflowed by massive confluent glaciers descending from the Highlands, and the whole of the great central valley of Scotland—the broad lowland country—is brimful of ice, forming one wide and far-stretching *mer de glace*. The effect produced in the old lake-bed of the Clyde basin by such an advance of the glaciers would no doubt be most destructive. Over broad areas the soft and incoherent masses of sand, mud, gravel, &c., which had gathered upon the bottom of the old lake would be ploughed up and intermingled with the other débris continually gathering and being pushed onward underneath the ice-sheet. But it might well be that in deeper hollows and in such ravines as intersected the path of the ice, some

here that the work I conceive to have been done by the Clyde was simply the denudation, or wearing away, of the *col* between two valleys, and the subsequent deepening and widening of those valleys.

portions of the lake-deposits might escape and receive a covering or cap of ground-moraine or till.

But a glance at the 'borings' given above (pp. 116, 120) will show that the buried hollows and ravines may contain more than one stony clay, separated by considerable depths of aqueous deposits. The latter [1] may point to periods when the ice vanished from the low grounds and retired to the mountain-valleys. Each time the Leven glacier advanced and choked up the Clyde valley, a lake would form over the region under review, and fresh-water beds would be deposited; each time the ice-sheet covered the whole country fresh masses of stony clay would accumulate in protected hollows and ravines. It is therefore unnecessary to call in the aid of the sea to explain for us the occurrence of those beds of gravel, sand, and mud which are intercalated with the stony clays in the buried valleys and depressions of the Clyde basin.

I have spoken of the outlet of the ancient glacial lake of the Clyde having been by the valleys of the Black Cart and the Rye. It is quite possible, however, and even highly probable, that the discharge at some periods may have been to the north-east by Kilsyth into the basin of the Forth. In attempting to picture the features of the land during successive stages of the glacial period, we have to bear in mind that after every descent of the glaciers very considerable changes would be effected here and there upon the configuration of the ground. In one place the level would be lowered by the abstraction of rock—in another it would be raised by the accumulation of superficial deposits. And it might quite well be that, owing to some such changes, the Clyde lake might during some stage drain into the Forth—for even now the difference of height between the watershed at Kilsyth and that of the Black Cart is only some fifty feet or so.[2]

[1] The thinner intercalated beds of sand, &c., may of course form part and parcel of the till itself: it is only the very thick intercalated deposits which, in a case of this kind, where the beds are not actually seen, we should feel inclined to consider as of lacustrine origin.

[2] The late Dr. Croll (*Climate and Time*, p. 485) did not agree with me that the intercalated beds in the buried channel of the Kelvin are fresh-water, because they closely resemble the similar intercalated deposits met with in the preglacial valley that extends from Kilsyth to Grangemouth (see above, p. 115), which he believed to be marine. But mere similarity of the deposits does not prove similarity of origin. The intercalated beds in the buried course of the Kelvin might be fresh-water, even although it could be demonstrated that those in the old ravine between Kilsyth and Grangemouth are marine. I still hold, therefore,

The actual certainty that such great disturbances of the drainage-system must have taken place during the glacial period has not received so much attention from glacialists as it deserves. Yet no one who gives the subject any consideration can fail to see how disturbances of the kind must have occurred in many other valleys besides that which I have selected for illustration. Long before the land-ice increased to such an extent as to overflow the Kilpatrick Hills, the Campsies, and the Ochils, many of the streams that drained into the Forth must have been dammed back by the great glacier which occupied the principal valley, and which in all likelihood extended many miles below Stirling, before the hills referred to were overtopped and buried. In attempting to read the records of the glacial period such considerations as these ought not to escape us; had they always been fully realised, perhaps we should have been less liable to set down every thick bed of silt, sand, or gravel, intercalated in boulder-clay, to the action of the sea.

It is quite certain, however, that marine deposits do sometimes occur intercalated among true morainic accumulations, and to these we shall refer presently. Meanwhile I must direct attention to some examples of interglacial fresh-water deposits which have already been briefly described.

that the physical evidence, so far as it goes, decidedly favours the views expressed above. In the first edition of this work I gave no opinion as to the origin of the aqueous deposits in the buried channel at Grangemouth. It is evident, however, that some are of older and some of later glacial age. All the deposits from the surface down to the bottom of the 'Red Clay' are marine and of later date than the till, and their average thickness is not less, as Dr. Croll has stated, than 85 ft., and in some cases 100 ft. With these, therefore, we have nothing at present to do – they are quite beside the question. The fact of their being marine throws no light whatever upon the origin of the aqueous beds intercalated with the underlying till. I see no reason, however, for believing the latter to be marine; they are more likely to be fresh-water, and were probably formed in the same way as the aqueous beds of the old Kelvin valley. Dr. Croll's chief objection to the fresh-water origin of the beds in question was the great depth from the surface at which they occur; he thought that if we held this belief we were forced to assume, 'not that the water formed by the melted ice was dammed back, but that the sea itself was dammed back, and that by a wall extending to not less than 200 to 300 ft., so as to allow of a lake being formed in which the deposits might accumulate; *assuming, of course, that the absolute level of the land was the same then as it is now.*' But this is what we are hardly entitled to assume; for not only have we no proof that the relative level of sea and land was the same then as it is now, but all the evidence goes to show that during the Ice Age there were frequent oscillations of level, and if the land stood in certain glacial times only 200 or 300 ft. above its present level, as there are many reasons for believing it did, then Dr. Croll's objection has no force.

CHAPTER X.

BEDS SUBJACENT TO AND INTERCALATED WITH THE SCOTTISH TILL—*continued.*

Interglacial and subglacial lakes—Crofthead interglacial beds—Climatic conditions of Scotland during interglacial ages—Fragmentary nature of the evidence not conclusive as to the climate never having been positively mild—Till at surface chiefly 'upper'—'Striated pavements'—Fossils in till—Duration of glacial and interglacial periods.

WHEN, as so frequently happens, the aqueous beds intercalated in the till contain no organic remains, we must often be in doubt as to whether they ought to be considered of interglacial age or not. We have good reason to believe that some are of lacustrine origin, and were accumulated at a time when glacial conditions still largely prevailed. Such would appear to be the case with the deposits of the Clyde valley in the neighbourhood of Glasgow, and with the similar accumulations which were exposed during the cutting of the railway tunnel at Neidpath. The succession of glacial and aqueous beds is expressive of climatic changes. Now and again, however, we encounter similar unfossiliferous water-assorted beds in the till, which were in all probability accumulated underneath an ice-sheet. Sometimes these are obviously torrential—they consist of coarse gravel and shingle, and indicate the existence of a subglacial water-flow. At other times they have all the appearance of lacustrine accumulations, and lead to the belief that underneath the ice-sheet which covered the broad lowlands of Scotland, temporary pools and lakelets, now and again, persisted for longer or shorter periods, until, owing to some change in the direction and pressure of the *mer de glace*, they vanished, to form again in other places. In our attempts to decipher the history of the aqueous beds which accompany the till, we must be careful, therefore, to distinguish between

subglacial and subaërial accumulations. In the case of the Clyde-valley beds and the Neidpath deposits we can be in little doubt—for the character and extent of these strata, and the physical conditions of the districts in which they occur, at once suggest their origin. And the same may be said of many other similar examples of unfossiliferous intercalated beds which might be cited.

But however strong may be the evidence of climatic change afforded by such beds, it must yield in importance to that which we obtain from fossiliferous aqueous accumulations. Take, for example, the interesting section of the interglacial beds of the Cowdon Burn (Fig. 35, p. 103). Here beds of clay, sand, silt, &c., are represented as completely enclosed in till. These showed lines and layers of peaty matter, and yielded, during the railway operations, an imperfect skull of the great urus, remains of the Irish deer and the horse, and other fossils. The beds are clearly of lacustrine formation, and their position proves that after a mass of till had been deposited by some great ice-sheet, a temperate climate ensued, when streams once more flowed down the valleys, and lakes occupied the hollows and depressions of the land--covered at that time with vegetation exactly comparable to that now clothing the Scottish Lowlands, and tenanted by oxen, deer, and horses. Finally, the presence of the overlying mass of till indicates that this mild period passed away, and was succeeded by severe arctic conditions, when thick ice again streamed over central Scotland.

Precisely the same inference as to change of climate is to be drawn from the other instances of interglacial beds with organic remains, mentioned at pp. 97—104; the stratified deposits in all these instances point to oscillations of temperature—to periods when the great ice-sheet disappeared from the low grounds, and shrank into a series of local glaciers among the mountain regions, or even melted away altogether.

As the interglacial fresh-water deposits occur in places often far apart, it is impossible to be certain that they are geologically contemporaneous. It seems probable, however, that they all pertain to one and the same stage, and that in them we have the relics of the old land-surface that existed before Scotland was overwhelmed by its last general ice-

sheet. It will be observed, however, that the assemblages of plants obtained at Cowdon Glen and Redhall betoken a climate like that which we now have in the Lowlands of Scotland, while at other places the occurrence of certain plants, and the presence of mammoth and reindeer, are suggestive of colder conditions. If one might draw conclusions from the scattered facts, one might compare Scotland during a certain stage of interglacial time to that tract of country which extends along the extreme southern limits of the Barren Grounds of North America—a region where a few firs and other hardy trees cover the drier slopes, and where carices and grasses grow luxuriantly enough in the sheltered valleys —those favourite breeding-places of the reindeer, which roam over the dreary deserts to the north. At another stage of the same epoch the climatic conditions were much more genial—the flora then clothing the Lowlands being identical with that which is still native. It was at this stage that Irish deer, horses, large and small oxen, and probably the mammoth also were occupants of the country.

Thus the Scottish interglacial beds, however unimportant they may be so far as bulk is concerned, are of the very highest interest, since their evidence amounts to a demonstration that the Ice Age was not one long uninterrupted period of cold conditions. Year by year that evidence has increased, and we may look forward to still more important discoveries. In the last edition of this work I remarked that the evidence of the Scottish interglacial beds, so far as it went, did not entitle us to infer that during their accumulation local glaciers may not have existed in the Highland valleys; 'and yet,' I added, 'we might be committing a grave error were we to assume that Scotland, in interglacial times, never enjoyed milder conditions than now obtain in the Barrens of North America.' The result of subsequent research has fully justified this remark. From what we now know of the interglacial deposits of other lands, we may expect to meet with still more remarkable evidence in the stratified beds accompanying the Scottish till. We must always bear in mind that these deposits are mere fragments. They have been preserved, for the most part, only in hollows sheltered from the ravages of the great ice-plough; and the interrupted and

patchy portions that remain are but the wrecks of what must once have been, in the broader valleys, wide-spread and continuous deposits. Each descent of the glaciers upon the low grounds would tend to effect the removal of such accumulations. Even during interglacial times streams and rivers would help to clear away and redistribute those beds of sand, gravel, and silt which the glaciers had spared—just as in our own day the streams are gradually excavating and washing away the materials that fill up old preglacial and interglacial ravines and watercourses. Moreover, we must not forget that if a really warm climate ever did supervene during interglacial times, such warm climate must have been followed successively by temperate, cold-temperate, and arctic conditions; and these last would consequently be the most fully represented of the series.

The reader will now appreciate what was meant when I stated, at the beginning of Chapter VII., that much, if not most, of the till now lying at the surface of the ground is not the oldest accumulation of the kind. For it is clear that a great proportion of the till that was formed during one cold epoch would be ploughed out by the ice-sheet that succeeded, while much of it would be so modified and rearranged as to become practically a newer till. Here and there, however, the older till has been preserved, and generally shows, underneath interglacial deposits and superincumbent till, a worn hummocky surface. It is by no means improbable also that the 'striated pavements' described in a former chapter may represent real 'breaks in succession.' The till overlying such pavements often differs to some extent from that in which the pavements are embedded. That the older till has been frequently preserved under overlying interglacial beds we have already seen; and it may well be that the 'striated pavements' represent the land-surface that existed prior to a glacial epoch—a land-surface glaciated and buried below the bottom moraine of the latest general ice-sheet.

It is also highly probable that the isolated mammoth tusks, reindeer antlers, bones, and fragments of oak and other trees which occur here and there like boulders in the heart of a mass of till, really belong to interglacial rather than to preglacial times. For it is evident that the till containing

these remains, which occurs at the actual surface of the ground, is more likely to have been laid down by the last general ice-sheet than to have been the product of an earlier epoch of glaciation. And consequently it seems most reasonable to infer, that the scattered organic remains referred to are relics of that interglacial stage which preceded the final invasion of the Lowlands by a great *mer de glace*.

The disappearance of an ice-sheet, which in the Lowlands of Scotland attained a thickness of nearer 3,000 ft. than 2,000 ft., could only be effected by a very considerable change of climate. Nor, when one fully considers all sides of the question, does it appear unreasonable to infer that the comparatively mild and genial conditions, of which the interglacial beds are memorials, may have endured as long as those arctic or glacial conditions which preceded and followed them. We have a difficulty in conceiving of the length of time implied in the gradual increase of that cold which, as the years went by, eventually buried the whole country underneath one vast *mer de glace*. Nor can we form any proper conception of how long a time was needed to bring about that other change of climate, under the influence of which, slowly and imperceptibly, this immense sheet melted away from the Lowlands and retired to the mountain recesses. We must allow that long ages elapsed before the warmth became such as to induce plants and animals to clothe and people the land. How vast a time, also, must have passed away ere the warmth reached its climax, and the temperature again began to cool down! How slowly, step by step, the ice must have crept out from the mountain fastnesses, chilling the air, and forcing fauna and flora to retire before it; and what a long succession of years must have come and gone before the ice-sheet once more wrapped up the hills, obliterated the valleys, and, streaming out from the shore, usurped the bed of the shallow seas that flowed around our island! Finally, when we consider that such a succession of changes happened oftener than once, we cannot fail to have some faint appreciation of the lapse of time required for the accumulation of our lower and upper boulder-clays and interglacial deposits.

The interglacial beds which have so far engaged our

attention are of fresh-water origin. They occur at all level in the valleys down to the neighbourhood of the sea. Indeed if the intercalated beds that help to fill the buried channel and depressions in the lower reaches of the Clyde basin be as I have tried to show they most likely are, of fresh-wate formation, then fluviatile and lacustrine beds of interglacia age occur even below the present sea-level.

In the next chapter I shall proceed to describe othe examples of interglacial deposits which are somewhat mor complicated than those already adduced, inasmuch as the afford distinct evidence of oscillations of the sea-level.

CHAPTER XI.

BEDS SUBJACENT TO AND INTERCALATED WITH THE SCOTTISH TILL—*continued.*

Marine deposits associated with till at Woodhill Quarry, Kilmaurs, Ayrshire; at Tangy Glen, Campbeltown; in south of Arran; at Oakshaw Hill, Paisley—Shelly till of Caithness; of Aberdeenshire; of Berwick; of Ballantrae, Ayrshire; of Wigtownshire; of Lewis.

IT will be observed that hitherto we have done no more than make a brief reference to the occurrence of undoubted marine beds in and underneath the till. For the sake of clearness, consideration of these intercalated and subjacent marine deposits has been delayed until now.

The first example I select is remarkable, because it shows how the beds in question are occasionally associated with deposits which are clearly of fresh-water origin.

Below a mass of till at Woodhill Quarry, near Kilmaurs, Ayrshire, which precisely resembles the tumultuous stony clays that underlie and overlie the fresh-water beds described in the preceding pages, remains of mammoths and reindeer and certain sea-shells have several times been detected during the quarrying operations. The first notice of these discoveries dates so far back as 1822, when Mr. Bald described[1] two elephant tusks as having been got (in 1817) at a depth of seventeen and a half feet from the surface. The tusks lay in a horizontal position, with some small bones near them, and the light-brown clay in contact with the bones was discoloured and emitted a very unsavoury odour when turned over. Mr. Bald mentions that several marine shells were found amongst the dark-coloured earth; but as the species were not determined, some doubt was subsequently expressed as to whether they were sea-shells or not.[2] Since the date of

[1] *Memoirs of Wernerian Society*, vol. iv. p. 64.
[2] *Trans. Geol. Soc. Glas.* vol. i. p. 69.

Mr. Bald's discovery, several other tusks (nine or ten), a portion of a molar tooth of an elephant, the antlers of a reindeer, and remains of insects and fresh-water plants have been met with at the same locality.[1] Dr. James Bryce showed[2] that all these remains came from beds underneath the boulder-clay, and Messrs. J. Young and R. Craig subsequently obtained[3] arctic marine shells from deposits occupying a similar position, which were disclosed during the operation of sinking a coal-pit about half a mile from the old Woodhill Quarry. The marine beds rested upon a fresh-water deposit. More recently Mr. Craig described[4] the discovery of mammoth remains and arctic marine organisms, met with in sinking a coal-pit at Drummuir, near Dreghorn, three miles south-west of Woodhill Quarry. In this pit the following succession was clearly exposed:—

4. Boulder-clay, 76 ft.: the normal till of the district.
3. Stratified sand and clay, 2 ft. These showed alternations of thin laminæ, and yielded shell fragments.
2. Sand, about 4 ft. This bed is charged with arctic shells and other marine organisms. Towards the top it becomes muddier, and it was in this muddy portion, about a foot from the top of the bed, that the mammoth's tusk was obtained.
1. Sand and gravel, 20 ft.; unfossiliferous, and contain throughout 'a small percentage of, apparently, West Highland rocks.'

Mr. Craig is of opinion that this section may be taken as showing the true succession of these interesting deposits, and that the 'peaty clay' referred to by previous writers was simply a darker coloured, muddy sand of the same character as that shown in the section. The presence of remains of reindeer and mammoth, and the occurrence of elytra of beetles and several fresh-water plants, are indicative of terrestrial conditions, however, and it is not improbable, therefore, that the deposit described by Mr. Bald may really have been of fresh-water origin. Mr. Craig, following Dr. Bryce, assigns the fossiliferous deposits to preglacial times.

[1] Mr. J. Young, of the Hunterian Museum, Glasgow, obtained seeds of *Potamogeton* and the aquatic Ranunculus by washing the mud which adhered to the reindeer's horn and filled the cracks of the elephant's tusks which had lain in the museum for half a century. *Trans. Geol. Soc. Glas.* vol. iii. p. 313. Mr. J. Bennie made a similar discovery of arctic ostracods and foraminifera by washing small fragments of clay which had been preserved along with the tusks described by Bald (*Trans. Royal Phys. Soc.* vol. viii. p. 451).

[2] *Quart. Journ. Geol. Soc.* vol. xxi. p. 213.

[3] *Trans. Geol. Soc. Glas.* vol. iii. p. 310.

[4] *Ibid.* vol. viii. p. 213.

But the results obtained during the examination of the ground by the Geological Survey show that the beds in question really occupy an intercalated or *interglacial* position, and that the cause of their sometimes being found to rest on the solid rock and not upon a lower mass of till is due to the irregularity of the surface on which the whole of the superficial accumulations have been deposited; for where the level of the rock slopes down far enough it passes below the horizon of the stratified beds, and a lower and underlying till then makes its appearance.[1] The very section given by Mr. Craig affords evidence of the interglacial character of the fossiliferous beds, for, as will be seen, these are underlaid by unfossiliferous gravel and sand containing small erratics which have come from the West Highlands. This stratum would thus appear to be one of those deposits which are so frequently associated with boulder-clay—either underlying or overlying it, or altogether taking its place. The presence of the erratics shows that the deposits have been derived from the disintegration of a pre-existing mass of bottom-moraine or till—the materials of which have been winnowed, sifted, and water-worn. Mr. Craig assumes that the bed in question is marine, and thinks that the erratics may have been carried from the north by sea-weeds! The deposits, however, are unfossiliferous, and therefore more likely to be of fresh-water origin. They are analogous, as we shall learn, to similar accumulations occurring again and again in these islands and in the glaciated regions of the Continent.

MM. Robertson and Crosskey have described[2] a section of boulder-clay with underlying stratified clay as occurring in Tangy Glen, near Campbeltown, at a height of 130 ft. above the sea. The till here exposed is 'of the usual character, stiff, compact, and full of stones, many of them distinctly striated.' It is quite unstratified, but exhibits one of those lenticular beds of sand, &c., which I have already mentioned as being a common enough feature of the Scottish till. Underneath the boulder-clay occurs a bed of laminated clay, showing a hummocky and denuded surface, as represented in the

[1] *Mem. Geol. Surv. of Scotland*; Explanation of Sheet 22, p. 29.
[2] *Trans. Geol. Soc. Glas.* vol. iv. p. 134; 'Monograph of the Post-Tertiary Entomostraca of Scotland,' *Palæontographical Society*, vol. xxviii.

accompanying woodcut, which I have borrowed from Messrs. Robertson's and Crosskey's paper. The underlying rock is not seen, but it is probable that the laminated clay rests directly upon it. A few fossil shells are found in this clay, among which there are some of an extremely arctic character. A number of species of ostracods also occur, which, according to Messrs. Robertson and Crosskey, 'have much in common with those found in the clays on the east coast of Scotland, which are held to represent more arctic types than those generally found in the west.'

In the south end of Arran deposits of clay, sand, &c., containing arctic and boreal shells, were discovered by

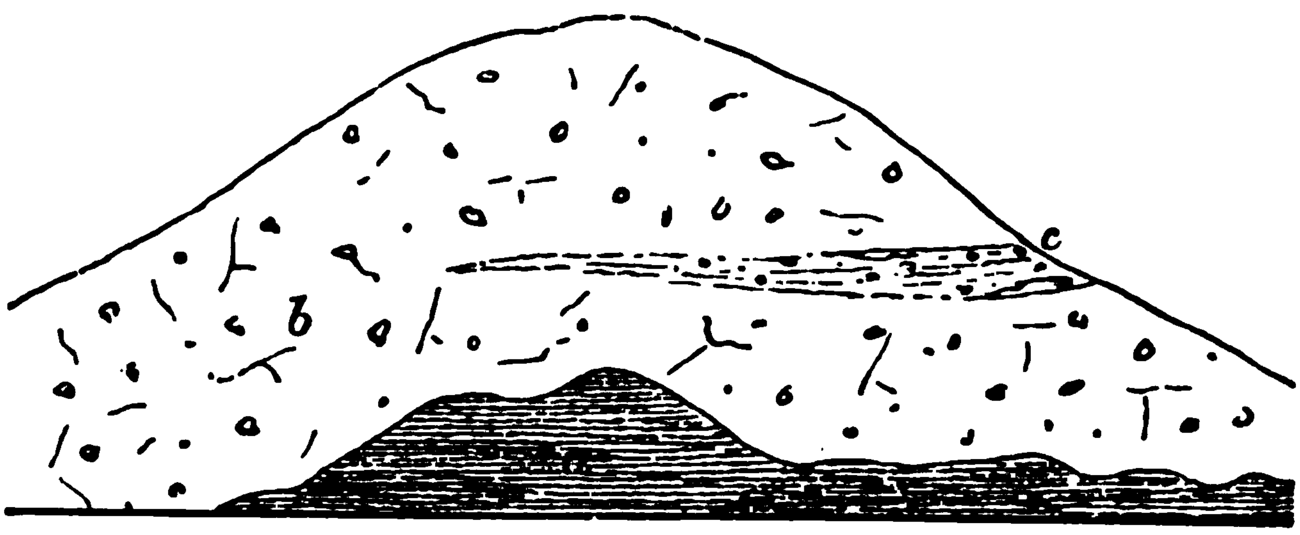


Fig. 40. Section of till in Tangy Glen, near Campbeltown. (Robertson and Crosskey.) *a*, bedded shelly clay; *b*, till; *c*, gravel, sand, &c., in till.

Rev. R. Boog Watson.[1] These deposits rest upon and are covered by boulder clay, and are exposed in section in the valleys of the Sliddery Water and the Cloinid Burn, a tributary of Kilmory Water. A good description of these sections is given by Dr. Bryce, who visited the ground in the company of Rev. Dr. Crosskey.[2] The shell-beds have yielded *Pecten islandicus*, *Cyprina islandica*, *Modiola modiolus*, *Astarte borealis*, *A. compressa*, *A. elliptica*, and other species. The underlying till is the usual tough, hard-pressed, amorphous mass, full of striated stones, the upper till being somewhat looser and more abundantly charged with large boulders. These sections I recently visited, and was able to confirm fully Dr. Bryce's observations. The upper till I

[1] *Trans. Roy. Soc. Edin.* vol. xxiii. p. 523.

[2] *The Geology of Arran*, &c. (1872), pp. 44, 181; 'Monograph of Post-Tertiary Entomostraca,' *Palæontographical Society*, vol. xxviii. p. 7.

followed over a wide area, and found that it presented all the characteristic features of that accumulation. It is the prevalent boulder-clay of the district, attaining a thickness in some places of 50 to 80 ft., so that the lower till is only exposed here and there in deep cuttings. I traced the shell beds to a height of 200 ft., and as some of the shells must have lived in depths of 10 fathoms and more, the minimum submergence indicated by the deposits cannot be less than 260 or 270 ft. below the existing sea-level. The shell-bearing deposits are somewhat disturbed, and appear to be to some extent re-arranged, so that possibly the shells do not always occupy the positions in which they were originally embedded. But if so then they have come from a higher level, for the boulder clay that overlies them speaks to an ice-flow from the hills behind. The actual amount of submergence, therefore, may have considerably exceeded 260 ft.

Dr. Fraser has described [1] the occurrence at Oakshaw Hill, Paisley, beneath a mass of unfossiliferous till, of a bed of shelly clay 'with a bed of *Mytilus edulis* on its surface.'

It will be observed that in the sections hitherto adduced the till is described as quite unfossiliferous, and not only so, but from its unstratified and tumultuous character there is no doubt that it cannot be distinguished from much of the till that occurs in the interior of the country. We come now to consider certain sections in which the till differs from that which we have hitherto been examining; and this difference we shall find consists chiefly in the presence of broken, crushed, and striated shells, which are scattered confusedly through the mass much in the same way as the stones and boulders with which they are associated.

One of the best known examples of a shelly till is that which covers a large part of Caithness. This deposit has been described by a number of geologists, but the best accounts of it are given by Mr. Jamieson [2] and by Messrs. Peach and Horne.[3] It occurs scattered over all the low

[1] *Trans. Geol. Soc. Glas.* vol. iv. p. 180.
[2] *Quart. Journ. Geol. Soc.* vol. xxii. p. 261.
[3] *Proc. Royal Phys. Soc.* vol. vi. p. 316. This paper contains a full list o the organic remains obtained from the Caithness till. The reader will also fin in it references to the literature of the subject.

grounds of Caithness, appearing deepest in valleys and other depressions, and attaining its greatest thickness in the neighbourhood of the sea, along the shores of which it forms cliffs in many places. It is generally of a dull, dark leaden-grey or slate-colour, and as a rule shows no trace of stratification. Its included stones and boulders are of the usual subangular blunted form, and many of them are well striated. In some places stones larger than one's head are rare, while in other places large blocks, more or less ice-worn, may be observed. The matrix is often a more or less tough gritty clay, but not infrequently it becomes sandier; and although it now and again preserves the former character over considerable areas and through a thickness of 100 ft. at least, it yet occasionally exhibits a number of irregular sandy patches, which, however, do not impart a stratified appearance to the mass. Now the stones are disseminated pretty equally through the deposit—again they are more or less aggregated, just as is the case in normal unfossiliferous till. The stones consist principally of fragments of the so-called 'Caithness flags'—rocks which belong to the Old Red Sandstone system and of which a considerable part of Caithness is composed.

In the sections along the eastern seaboard, according to Messrs. Peach and Horne, there is a comparative absence of ordinary-sized blocks of these rocks—the till being, as a rule, not very stony, and containing only small well-rounded pebbles. When the deposit is followed inland, however, the fragments derived from the flagstones increase in number and size. It is further noteworthy that the larger blocks lie with their longer axes in a south-east and north-west direction. That the till has travelled towards the north-west is shown by the transport of certain local rock-fragments. But the direction of transport is still more clearly indicated by the presence of many boulders belonging to rocks which are foreign to the Caithness plain. Messrs. Peach and Horne mention amongst these, granite, felsite, diorite, gneiss, mica-schist, quartzite, various rocks and fossils belonging to the Jurassic system, chalk and chalk-flints, fragments of jet &c. The Jurassic rock-fragments are of precisely the same character as the fossiliferous rocks of that age which occur in a narrow strip on the coast of Sutherland between

Golspie and Helmsdale; and although Cretaceous strata are not met with *in situ* on the shores of the Moray Firth, they are believed to exist on the bed of that basin. Throughout this till occur numerous broken shells and other marine organisms, many of the shell-fragments showing fine glacial striæ. It is not common to meet with a perfect specimen, but several shells have been found with both valves complete, and more or less well-preserved single valves are not very rare. In general, however, they are mere fragments, and are scattered through the clay in the same irregular manner as the stones and boulders. It is noteworthy that they show a curious mixture of arctic, boreal, and southern forms. Amongst them only a small number are characteristic of the littoral zone, the most abundant being species whose habitat lay in deeper water. It may be added that the shells occur most plentifully along the eastern seaboard of Caithness—becoming gradually scarcer as the till is followed inland towards Thurso and Reay.

Messrs. Peach and Horne have recently shown that a similar shelly boulder-clay occurs in the Orkney Islands. The numerous shell-fragments are often smoothed and striated in the same manner as the glaciated stones with which they are associated.[1]

In the north-east of Scotland, as in Aberdeenshire, Banff, Elgin, and Nairn, interrupted sheets of clay, sand, and gravel, containing marine shells, occur at various levels up to a height of rather more than 500 ft.[2] These rest in many places upon boulder-clay, and are now and again covered by a second boulder-clay. They vary much in thickness, attaining in some places a depth of 40 to 60 ft. and more. In Nairn, Elgin, and Banff, as Mr. Horne informs me, the shelly silts, clays, and sands are seen resting upon a dark shelly boulder-clay, and when followed inland are found to be overlapped by a reddish-brown boulder-clay of the normal unfossiliferous character.

Some years ago, Mr. J. Fraser described the occurrence of a shelly clay underneath boulder-clay at Clava, in the

[1] *Quart. Journ. Geol. Soc.* vol. xxxvi. p. 656; *Trans. Geol. Soc. Edin.* vol. vi. p. 309.

[2] Jamieson, *Quart. Journ. Geol. Soc.* vol. xxxviii. pp. 145, 160; Wilson, Expl. of Sheet 87, *Geol. Survey of Scotland.*

valley of the Nairn. The shelly clay, according to him, was *in situ*, and indicated a submergence of over 500 ft. prior to the accumulation of the overlying boulder-clay[1]—a conclusion which was subsequently supported by the late Dr. Crosskey.[2] Doubt having since been expressed as to whether the shelly clay was really *in situ*, a Committee, appointed by the British Association, duly investigated the beds, and found the sequence of deposits to be as follows:—

1. Surface soil and sandy boulder clay	43 feet
2. Fine sand	20 „
3. Shelly blue clay, with stones in lower part . . .	16 „
4. Coarse gravel and sand	15 „
5. Brown clay and stones	21½ „
6. Old Red Sandstone beds.	

Beds 1, 2, 3, and 4 were exposed in open section, and could be carefully studied, but unfortunately the excavations made by the Committee did not lay bare bed 5, which was only bored through.[3] The shells obtained from bed 3 are chiefly shallow-water species, and 'on the whole are remarkably well preserved, many retaining their epidermis. They are neither rubbed nor striated.' 'Though the fauna is not intensely Arctic, it implies colder conditions than the present.' This shelly bed reaches a height of 503 ft. above the sea, and appears to be continuous for a distance of at least 190 yards in a well-nigh horizontal position. It contains a few small stones, usually well rounded, and amongst these is a small block of grit, which may have come from the Jurassic strata near the Sutors of Cromarty. The stones in the overlying boulder-clay, and the trend of the glaciation of the neighbourhood, indicate an ice-movement from southwest. The majority of the Committee (MM. J. Horne, T. F. Jamieson, David Robertson, and J. Fraser) are of opinion that the shell-bed is *in situ*—that the marine organisms lived and died where their shells are found

[1] *Trans. Geol. Soc. Edin.* vol. iv. p. 136.

[2] *Trans. Inverness Field Club*, vol. iii.

[3] I understand it was feared that the walls of the pit might collapse and smother the workmen. The bed not having been exposed the Committee express no opinion as to the nature of the 'brown clay with stones.' I do not suppose there can be much doubt that it is 'boulder-clay.' There is no other kind of 'clay with stones' met with in Scotland in such a position and of such a thickness. Nevertheless it is to be hoped that we may yet have the section opened up and this 'brown clay with stones' examined.

—and that subsequently the region was overflowed by glacier-ice, which deposited the superjacent boulder-clay. The minority (MM. D. Bell and P. F. Kendal—the latter of whom appears never to have seen the deposits) incline to the view that the shelly clay is not *in situ*, but has been dragged or pushed into its present position by a *mer de glace*—in short, the shell-bearing beds, according to them, form a great erratic, which has travelled underneath an ice-sheet from the basin of Loch Ness. Glacier-ice has played many strange freaks, but one may be excused for doubting whether it is equal to this remarkable performance. I cannot think it possible that a sheet of clay and sand, measuring 190 yards at least in diameter, could be dragged forward underneath an ice-sheet, for a distance of twelve miles from the sea-level up to a height of 500 ft., and yet manage to preserve its horizontality, and to exhibit no trace of deformation or disturbance. Messrs Bell and Kendal appear to have adopted this peculiar explanation of the evidence because they cannot find elsewhere any proofs of a submergence of the land during glacial times. They think that if Scotland had ever been depressed to the extent of 500 ft. the sea would have left abundant evidence of its former presence. Had such a degree of submergence ever taken place prior to the advance of a general ice-sheet, surely we should find the ground-moraine of that ice-sheet more or less abundantly charged with relics of marine life? But this does not necessarily follow. A depression of 500 or 600 ft. would drown only a narrow belt of coast-land and a relatively small area in the midlands of Scotland, and the submergence may not have been long-continued. Hence marine deposits may never have been accumulated to any extent at the higher levels of the drowned regions. Or, again, the conditions may not have favoured the abundant development of marine life. But even if marine life had been prolific and the old sea-bottom more or less well covered with sedimentary deposits, it does not follow that the boulder-clay of the succeeding *mer de glace* should now contain any shells. No doubt, when the ice first began to plough up the shelly clays and sands its ground-moraine would necessarily be abundantly charged with organic débris—it would be a 'shelly boulder-

clay.' We must remember, however, that a glacial epoch endured for a considerable period of time, and that so long as the ice-movement continued subglacial erosion would be carried on, and ground-moraine would travel outwards from what are now our coast-lands. Thus, by-and-by the supply of shelly deposits at and below the level of 600 ft. would tend to become exhausted, and the boulder-clay continually passing outwards from the land would eventually contain no shells. The boulder-clays which cloak our maritime regions must belong for the most part to the closing stage of glacial activity. The ground-moraine formed during the earlier stage, when the ice-sheet first advanced over the shelly sands and clays, must now lie beyond our coast-line. We need not feel surprised, therefore, that only small patches of the shelly sands and clays should have been preserved, or that the boulder-clays of our coast-lands should so seldom contain any marine organic remains. The shelly till of Caithness was formed under exceptional circumstances. The ice that overflowed that region reached it only after travelling continuously for a long distance across a sea-bottom. It is worthy of note, moreover, that the shells in that till become gradually less common as we recede from the east coast, suggesting, as I think, that they tended to be crushed and obliterated as the till was dragged forward. It is for the same reason, probably, that so few relics of terrestrial life have been preserved in our till. We cannot doubt that vegetation of some kind covered the land, and that sheets of peat and beds of fluviatile and lacustrine alluvia existed before the advent of an ice-sheet. Yet how excessively rare is the occurrence in the till of any trace of terrestrial life! Now and again a mammoth's tusk or a sorely rubbed fragment of wood has been met with—and that is all. With few exceptions the only shelly tills that are known are those which have been laid down by ice moving out from what is now the sea-bottom to the land.[1] The gradual disappearance of shells from the till of Caithness, as that deposit is followed from the east coast in a north-westerly direction, finds a

[1] The shelly till of the Loch Lomond district belongs, as I believe, to a later date than any of the shelly boulder-clays referred to above. It has obviously not travelled far, and appears to have been deposited by a local glacier.

parallel in East Anglia. On the coast of Norfolk the boulder-clays contain numerous shells and shell-fragments and, now and again, patches of an older shell-bed which are obviously erratics. There, as in Caithness, the land has been invaded by ice approaching from the sea. But when the glacial accumulations are followed inland in the direction of ice-movement, that is, towards the south-west, shells and erratics of shelly clay disappear. This, I need hardly say, is not the case with the normal stony erratics that accompany the shells. The latter became crushed and obliterated, while many of the former travelled onward to the terminal front of the ice-sheet in southern England. The consideration of

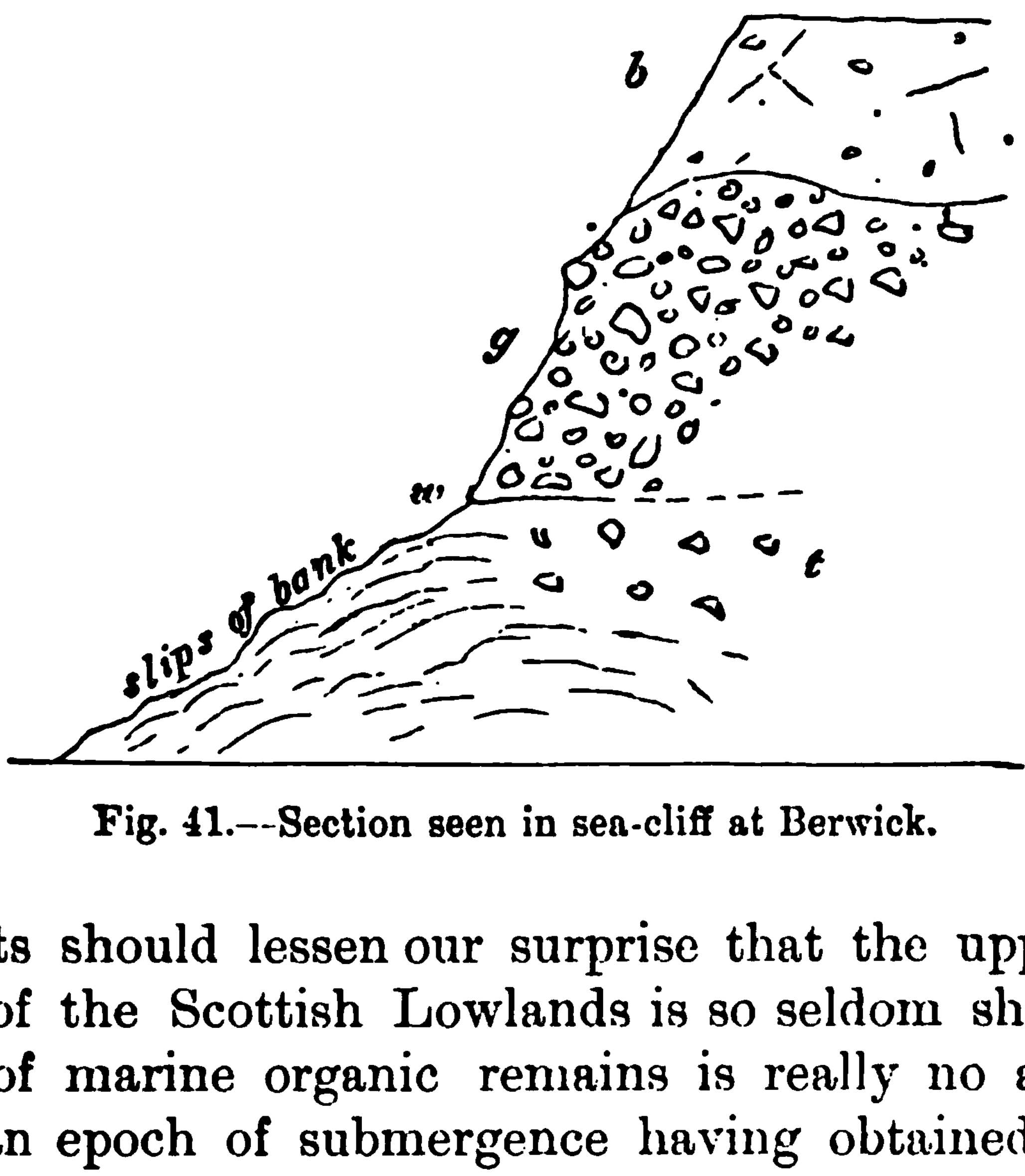


Fig. 41.—Section seen in sea-cliff at Berwick.

these facts should lessen our surprise that the upper boulder-clay of the Scottish Lowlands is so seldom shelly—the absence of marine organic remains is really no argument against an epoch of submergence having obtained prior to the formation of that clay.

Having given some description of the well-known shelly till of Caithness, it is not necessary to do more than cite a few other localities where shells and shell-fragments occur in boulder-clay. In the sea-cliffs at Berwick some good sections may be observed, of which the annexed section may be taken as an example. At the bottom may be noted a reddish clay stuck full of scratched stones (*t*), and which, as far as I have noticed, contains no shells. Owing, apparently, to the

copious percolation of water (at *w*) between it and the overlying looser deposits, it is rendered soft and incoherent. The immediately superjacent bed consists of boulders and coarse shingle, in a sandy clay matrix (*g*). The stones look water-worn, but are more or less angular and blunted, and some are striated. The base of this shingle-bed is not well seen, and consequently the junction-line between it and the till is not distinctly visible. This arises from the action of the springs, which are continually producing little slips of the bank. Overlying the coarse shingle occurs a dark reddish-brown clay (*b*) with a few scattered stones, which are in other places more closely aggregated. They are generally ice-worn, but some show no traces of glaciation. In this bed broken and worn shells occur, but they are not common. In other parts of the cliff irregular beds of sand are intercalated with *g* and *b*, and sometimes the whole of the rock-covering consists of a red boulder-clay, often very coarse, overlaid with beds of sand and clay.

Shelly boulder-clay may be seen in the old sea-cliff between Bennane Head and Ballantrae, Ayrshire;[1] and some good sections are exposed upon the coast of Wigtownshire,[2] as at Clanyard Bay, and at the south end of Port Logan Bay, both on the west coast of the Mull of Galloway, and again at Monreith tileworks,[3] about two and a half miles south of Port William on the shores of Luce Bay. In the same county, at the Cleshmahew tileworks, one mile south of Stranraer, shelly till is covered by brown laminated shell-bearing clay, which in turn is overlain with an upper stony clay containing apparently no fossils. Mr. Irvine, who surveyed the western districts of Wigtownshire, states that fragmentary shells occur at various places in the stiff till of the low grounds, as at Lady Bay, Innermessan, and Sandhead on the shores of Loch Ryan.[4]

In the north of Lewis we find the sea-cliffs in some places formed of glacial deposits, as on the east coast at the Port of Ness, and on the other side of the island between the points

[1] *Mem. Geol. Surv. Scot.*, Expl. of Sheet 7, p. 14.
[2] *Op. cit.*, Expl. of Sheet 1, p. 8; 'Monograph of Post-Tertiary Entomostraca of Scotland,' *Palæontographical Society*, vol. xxviii. p. 69.
[3] *Mem. Geol. Surv. Scot.*, Expl. of Sheet 2, p. 9.
[4] *Op. cit.*, Expl. of Sheet 3, p. 23.

of Cobha Sgeir and Sinntean. The accompanying sections show the general succession of the beds. In Fig. 42 two beds of boulder-clay, with intermediate deposits of sand, gravel, and clay or silt, are seen. The lower boulder-clay bed rests upon gneissose rocks, which in some places have a smoothed surface under the clay, although they are more often, perhaps, somewhat rough and broken. I found that throughout Lewis the gneissose rocks seldom preserved their striæ.[1] Even where the *roches moutonnées* looked exceedingly fresh, it was rare to detect the 'ghosts of scratches.' I often observed, however, that the quartz veins which projected above the surface of the rounded rock-faces were well

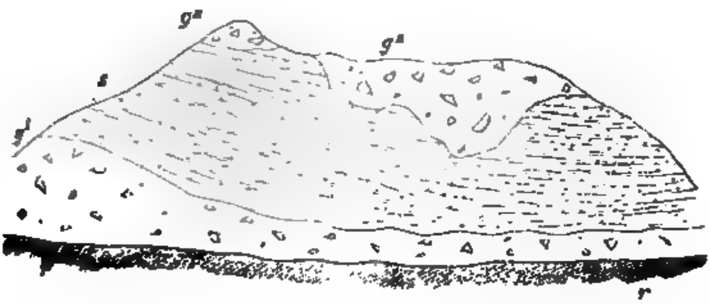


Fig. 42.—Boulder-clay and associated deposits, Traigh Chrois, Island of Lewis. *r*, Gneiss. *g*¹, *g*², Lower and upper boulder-clay. *s*, Sand, gravel, and clay.

striated. This was particularly observable on the sides of Suainabhal and other mammillated hills in the south; and in one place, where the till had only been recently stripped from the ground, I noticed that the gneiss was beautifully polished and striated over an area of several square yards, although the rock-faces immediately adjoining, which had long been exposed to the action of the weather, had lost all their striæ and presented only a smoothed outline. From these facts it becomes apparent that the coarse gneiss of Lewis is not well adapted to preserve the finer etchings of the ice-chisel. Rain and frost soon corrode its surface, and the rock then crumbles away, so as to leave its quartz veins standing out in relief; and these, as I have said, often show

[1] See a paper by the author, *Quart. Journ. Geol. Soc.* vol. xxix. p. 532.

striæ.[1] In Harris and the other islands of the Outer Hebrides, however, I met with glaciated rock-surfaces and rock striæ again and again,[2] as is shown upon the map, Plate IV. But to return to our drift section.

The lower bed of boulder-clay is a dark greyish brown, sandy, or earthy clay, quite unstratified, with numerous blunted stones and boulders. These consist mostly of gneiss of a kind which did not readily admit of striation, consequently only a few of the finer-grained, harder, and more compact stones show any striations. At Port of Ness this boulder-clay is of a dark brown colour, and often very sandy, and contains patches of sand. Here some of the stones are well striated; and many boulders of Pre-Cambrian red sandstone and conglomerate were seen in the clay. But

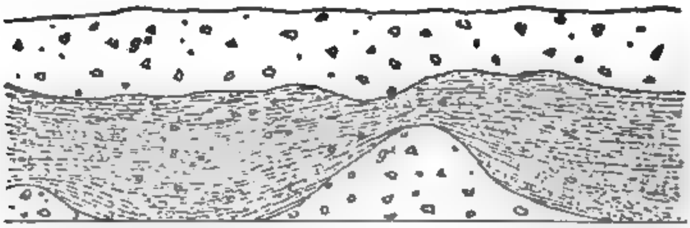


Fig. 43. - Boulder-clay and associated deposits, Traigh Chrois, Island of Lewis. g^1. g^2, Under and overlying boulder-clay. *s*, Fine sand and clay partings, with a few scattered stones.

the most remarkable feature of this stony clay is the presence of broken arctic and boreal shells, which occur in an irregular manner through the mass The upper surface of the boulder-clay is denuded—a character better shown in Fig. 43, which is taken from the same locality. The stratified beds contain shells, most of which are in a fragmentary state, but some perfect specimens may be detected. They belong to arctic and northern species. A few stones occur here and there in the beds. In some sections these beds consist of an upper

[1] There are some remarkable changes in the 'strike' of the gneissic rocks of Lewis: thus in the neighbourhood of Stornoway the strike is north-east and south-west, and the dip is to south-east. West of Stornoway, in the central district of the island, the strike is only a little north of east and south of west—the dip being a little east of south. In the Great Bernera, all along the shores of Loch Roag, and throughout the Uig district, the strike is distinctly north-west and south-east, with a prevalent dip to the north-east.

[2] *Quart. Journ. Geol. Soc.* 1878, p. 819.

series of sand and gravel deposits, more or less distinctly separated from an underlying deposit of imperfectly laminated dark blue and grey clay and silt or mud (as in Fig. 44). Shells occur in both. At Port of Ness the stratified deposits are represented by coarse gravel and shingle with large rolled boulders; the whole very rudely bedded, but containing worn fragments of shells. At Traigh Shuainaboist the stratified beds show occasional contortion. Above these deposits comes another mass of unstratified boulder-clay, which in some places is of a reddish-brown colour, and somewhat more sandy in texture than the lower mass, already described. But it is very irregular. Thus at Traigh Shuainaboist it is a tumultuous, unstratified, dark blue silty clay, very tough in places, and shows irregular veins and

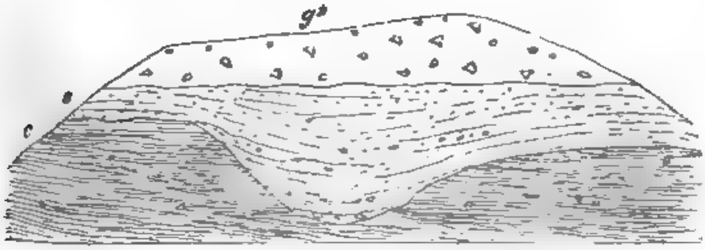


Fig. 44.—Boulder-clay overlying stratified deposits, Traigh Chrois, Island of Lewis. g^2, Boulder-clay. *s*, Sand and gravel. *c*, Clay and silt.

bands of sand and gravel. The boulders and stones are unequally aggregated in parts, and are of all sizes up to blocks four or five feet across; most of them being angular and subangular, and not often showing striæ. Amongst the prevalent gneissic fragments are a few of red grit and sandstone. Here and there, as at Port of Ness, this boulder-clay contains fewer large boulders, and the stones are scattered more equally through the mass. At this latter place it is not so stony as the underlying till, and seems, moreover, to graduate down here and there into the intermediate stratified beds. Broken shells occur in the upper boulder-clay, but they appear to be somewhat rare. It may be worth noting that towards the north end of the sea-cliff at Traigh Shuainaboist a mass of coarse shingle caps the cliff and passes down into sandy boulder beds, some stratified

L 2

portions of which consist of shelly grit, gravel, and sand.[1] The line of junction between the upper boulder-clay and the underlying sand and silt beds is, as a rule, well defined, but occasionally, as I have said, one may note a passage or graduation of the former into the latter.

I have been thus minute in my account of these drift sections because, as we shall see by-and-by, they seem to throw considerable light upon the origin of similar shelly boulder-clays that occur upon the mainland.

[1] I ought, perhaps, to mention that here and there the glacial beds are overlaid with sand and gravel full of rolled shells of species that are even now living in abundance round the coasts of Lewis. These beds, however, are much more recent than the glacial deposits—they belong to the 'Raised Beach' series, and, therefore, it would only tend to confusion were I to describe them along with the deposits which we are at present examining.

CHAPTER XII.

BEDS SUBJACENT TO AND INTERCALATED WITH THE SCOTTISH TILL—*continued.*

Climatic changes indicated by marine interglacial beds—Origin of the shelly till —Dr. Croll on shelly till of Caithness—Observations of Messrs. Jamieson, Peach, and Horne—Deflection of striæ in north-east maritime districts; in the estuary of the Tay and in Fife; in the estuary of the Forth and in Haddingtonshire; in the valley of the Tweed and maritime districts of Northumberland—Origin of the glacial deposits of Lewis.

WHEN marine organisms occur in a stratum in such a way as to show that they must have lived and died where we now find them, we are compelled to infer that the land must have been submerged to a certain extent at the time these organisms flourished. But if the state of the fossils and the mode of their occurrence be such as to indicate that the creatures could not have existed in the position their shells, &c., now occupy, then the proof they furnish of a former submergence is by no means so satisfactory. The deposits that formed the subject of the preceding chapter present us with a number of examples of both kinds of evidence. Sometimes the proofs of former inroads by the sea upon the land are indisputable, at other times the presence of sea-shells is no proof of submergence at all. An examination of the evidence will make good these points.

It will be remembered that underneath a mass of till at Woodhill Quarry, near Kilmaurs, there occur certain marine and fresh-water deposits which rest directly upon the rocks. From this it might at first be inferred that these latter deposits are of preglacial age; but when we bear in mind that the central Lowlands of Scotland have been subjected to the grinding action of two successive ice-sheets, we must admit that very strong evidence is required to prove that any portion of the old preglacial surface of that country has

been preserved. It is more reasonable to believe th deposits like those under the till at Woodhill Quarry belon to an interglacial stage—to that epoch, namely, that pr ceded the final invasion of the Lowlands by a general *mer d glace*. This belief, so reasonable in itself, is justified by th fact that in the neighbourhood of Woodhill the stratifie beds that underlie the till have yielded erratics, and a themselves in certain places underlaid by another deposit o boulder-clay. The succession of changes to be inferred from the evidence is therefore as follows:—First, a period o arctic rigour, when the whole country was covered with ic underneath which was formed the lower till; second, period when the ice melted away from the low ground and retired to the mountains, and when streams flowed i the grassy valleys, and the climate was such as to nouris herds of the mammoth and the reindeer; third, a perio when the sea gained upon the land to a height of 100 f at least, and when molluscs of arctic and northern specie lived and died and were buried in the silt and sand tha gathered over the peaty accumulations in which the remain of the old mammals were stored up: fourth, a period whe arctic conditions again prevailed, and another ice-sheet crep out from the mountains and covered the low grounds wit its *moraine profonde*—the upper boulder-clay.

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I must now discuss the origin of the shelly tills and the

beds with which they are associated. The occurrence of broken shells in boulder-clay has always been a puzzle—many geologists being inclined to support the view of the marine origin of such deposits. But there are insuperable objections to this view. For in most cases the shelly tills do not differ in general structure and appearance from unfossiliferous boulder-clay. They contain perhaps a greater percentage of sand and rolled gravel and grit, and are as a rule less tough than the hard unfossiliferous till of the interior, and their included stones and boulders are certainly not generally so well ice-worn and striated as those of the till of inland districts. But leaving their fossil contents for the moment out of account, they can yet be paralleled by many deposits of unfossiliferous till, more especially by those somewhat looser and less tenacious masses that overlie most of the interglacial beds described in the preceding chapters. And if these upper or overlying deposits of till be of the nature of true *moraine profonde*, then the shelly tills must be so likewise. They certainly bear no resemblance to what we conceive iceberg-droppings to be; but their included erratics have evidently travelled in one and the same direction, and this coincides with the trend of the underlying rock-striæ: moreover, the colour of the clay is influenced by the nature of the subjacent rocks in the same way as the normal till of the interior. But these and other points will come out as we examine the evidence.

I have stated at page 85 that the Scottish ice coalesced on the floor of the North Sea with the ice that streamed out at the same time from the Scandinavian peninsula. Certain proofs of this extraordinary junction of these ice-sheets may now be brought forward.

It was formerly maintained that the boulder-clay of Caithness was a marine accumulation—that it was deposited at a time when the north-east of Scotland was submerged and traversed by much floating ice. But that opinion has, for a number of years, been definitely abandoned, and it is now admitted that the till in question is of precisely the same origin as normal boulder-clay. Dr. Croll was the first to deny the marine character of this remarkable deposit, and to show that the presence of the shells was really no proof

of submergence. He pointed out that all the phenomena could be accounted for by a movement of glacier-ice from the south-east, a direction which at first sight seems impossible; he showed, however, that the great ice-sheet coming from Scandinavia could not possibly have broken up into icebergs in the shallow North Sea, but must have coalesced with that of Scotland; and this junction would necessarily result in the deflection of the large glaciers that streamed out from the north-eastern districts of our island. The natural direction of the Scottish ice was undoubtedly down the beds of Moray and Dornoch Friths away to the north-east, but its path would be obstructed by the vast *mer de glace* that already occupied the bed of the North Sea. Instead of flowing, therefore, in that direction, it would be forced to turn to north-west, and to creep across the broad flats of Caithness. In doing so it would necessarily drag along with it the silt and mud and marine organisms that were previously distributed over the sea-bottom. Mixing up these with the usual stones and débris that gathered underneath as it journeyed on, it would thus amass a bottom-moraine through which broken and scratched shells would be dispersed in the same way as stones and boulders. This explanation, it will be observed, accounts for the occurrence in the Caithness till of bits of Cretaceous and Jurassic rocks, for there is every reason to believe that areas of these strata occupy the bottom of the Moray Frith. Along the coast of Sutherland a strip of Jurassic strata is seen, and the probabilities are that these rocks are succeeded out to sea by Cretaceous deposits, from which the chalk fragments in the Caithness till may have been derived.

The truth of Dr. Croll's sagacious inference was subsequently established by my brother and Mr. B. N. Peach, whose observations put it beyond doubt that the north-east part of Caithness has really been overridden by land-ice flowing in a direction from south-east to north-west (Plate I.). Before I quote what Mr. Peach says, I may mention that the dark greyish shelly till which is found scattered over all the low grounds of Caithness does not extend farther west than a line drawn between Berriedale on the south to near Reay on the north coast of the county

West of this line the till contains no shells, is of a reddish colour, and includes no stones which may not have been derived from the interior of the country. Mr. Peach remarks,[1] 'Near the Ord of Caithness and on to Berriedale the striæ pass off the land and out to sea; but near Dunbeath, six miles north-east of Berriedale, they begin to creep up out of the sea on to the land, and range from about 15° to 10° east of north. *Where the striæ pass out to sea* the boulder-clay is made up of the materials from inland and contains no shells, but *immediately the striæ begin to creep up on to the land* then shells begin to make their appearance; and there is a difference, moreover, in the colour of the clay, for in the former case it is red and incoherent, and in the latter hard and dark coloured.'

I may add that these observations were confirmed and extended by Mr. Peach in company with Mr. Horne, during a later examination of the district, and for details the reader is referred to their admirable paper already cited.

Dr. Croll further suggested that the headland of Fraserburgh was probably overflowed by ice coming from the south-east. I think, however, it is more likely that in this case the ice came from the west. The fragments of chalk and oolite which occur in the superficial deposits at so many different points along the shores of Elgin, Banff, and the north of Aberdeenshire, have more probably been derived from rocks lying at the bottom of the Moray Frith than from any submarine district south-east of Fraserburgh. Mr. Jamieson has also pointed out that along the coast from Banff to Peterhead the prevailing colour of the till is quite like that of Caithness. Moreover, the striæ indicate the former presence of ice moving out to sea by way of the Moray Frith, but compelled to hug the coast in obedience to the same opposing power that forced the ice to overflow the flats of Caithness.

Reference has already been made to the fact that the Orkney and Shetland Islands have been glaciated by ice moving from the North Sea towards the Atlantic. The observations of Messrs. Peach and Horne have shown that

[1] *Climate and Time*, p. 453.

this is demonstrated alike by the trend of glacial striæ, the position of *roches montonnées*, the distribution of the boulder-clay in the islands, and by the direction in which the stones in that deposit have travelled. The Orkney Islands would appear to have been traversed by ice coming from Scotland, while the Shetlands were overwhelmed by the great Scandinavian *mer de glace*. From Dundee northwards all the rock-striæ on the low grounds along the eastern seaboard have a tendency to turn to the north-east. South of Dundee, however, the direction of glaciation on the coast-lands is first easterly and then south-easterly. We may note also that instead of trending down the estuary of the Tay they strike right across the Fife hills; and when we trace them along the southern shores of the Firth of Forth they gradually lead us away to south-east, until at Coldingham we find them running parallel with the coast-line. Again, if we follow the valley of the Tweed we shall meet with the same appearances. In this valley the ice flowed at first towards the north-east (about Melrose), but as it crept farther down the valley it began, for no apparent cause, to turn away, first to east, then to south of east, until at last it rounded the northern spurs of the Cheviots, and thereafter flowed right away to the south-east, hugging the maritime district of Northumberland.

Now such remarkable deviations from what must have been the natural course of the Scottish ice can only be accounted for by inferring the presence in the North Sea of the Scandinavian *mer de glace*. With that vast sheet blocking up its outlet to sea, the Scottish ice was forced away to the south-east and compelled to invade Northumberland, just as, for similar reasons, it overflowed Caithness and the Orkney Islands.

In the sequel, abundant evidence will be adduced to show that the passage of the British ice out to sea was blocked all along the eastern seaboard of England by the Scandinavian *mer de glace*, which not only succeeded in deflecting the British ice-flow out of its natural course, but actually invaded the English Midlands.

We see, therefore, how the appearance of sea-shells in a tumultuous unstratified till is no evidence in favour of that

till having been formed in the sea. The broken shells occur precisely in the same way as stones and boulders, and hence they yield similar evidence as to the trend of the great ice-sheet. Boulders of Perthshire granite in the till of Fife indicate an ice-flow from the Highlands towards the south-east—broken shells in the till of Caithness point to an ice-flow from the sea-bottom to the north-west.

It must be observed, however, that in Banff and Aberdeenshire, beds of silt, &c., containing sea-shells have been noted underneath the till in various places. It is highly probable, therefore, that considerable portions of the low grounds of Scotland were actually submerged, or had only recently been vacated by the sea, at the time when land-ice began to creep over Caithness, and that some of the materials (both clay and shells) of the Caithness till may possibly have been derived from the demolition of those soft marine deposits which cloaked the low-lying parts of the country before the ice-sheet attained its great development. But, for the reasons already given, the materials from this source would soon be exhausted, and the probabilities are, therefore, that most of the shells, &c., have been dragged in from the floor of the sea. There is no evidence to show that the shelly silt and clay, &c., which here and there occur below the shelly tills are of preglacial age. It is much more likely, as Mr. Jamieson has remarked, that they are of more recent date than the earliest stage of the glacial period. In this connection it is much to be regretted that the Committee of the British Association, who investigated the shelly clay at Clava, did not lay bare the section to the bottom. Had they done so, we should have learned what is the precise nature of the 'brown clay with stones,' which underlies the shell-beds. It is described as twenty-one feet in thickness, and may well be of the nature of a ground-moraine; it is hard, indeed, to conjecture what else it can be. But until it has been actually examined, we must remain in doubt. I believe all the shell-beds which are met with, underlying boulder-clay, are of interglacial age—most of them probably accumulated towards the close of such an epoch, when the climatic conditions were becoming boreal and arctic. That this is not an unreasonable view will, I hope, appear when

we have considered the conditions under which the deposits in the north of Lewis have been accumulated.

The Outer Hebrides, as I have already mentioned,[1] have been glaciated across their whole breadth by land-ice, which poured out from the rugged wilds of Skye, Ross, and Sutherland, filled up the Minch, and thereafter traversed the islands in a general direction from south-east to north-west. The course followed by the ice is proved not only by the position of *roches moutonnées* and other glaciated surfaces, but also by the stones in the till. Thus boulders of red sandstone and conglomerate which could not have been derived from any place nearer than the neighbourhood of Stornoway, occur in the till of the west side of Lewis. None of the till of the interior, however, contains a vestige of shells, nor does it ever assume the character of a dark clay, like the shelly tills which I have described as occurring in the extreme north of that island. Indeed, throughout the whole Outer Hebrides the average character of the till[2] is that of a greyish earthy or clayey grit, often hard, as if it had been subjected to great pressure, and always more or less thickly charged with blunted angular and subangular stones, among which only the finer grained ones show striæ. Such is the general aspect of the deposit on east and west coasts alike. It is particularly noteworthy that this unfossiliferous till is composed of local materials only. Few, if any, erratics derived from Skye or the mainland occur anywhere save in the north of Lewis. They are conspicuous by their absence in all the other islands. The shelly tills are likewise restricted to northern Lewis. But a dark grey clay, with shells, occurs in the Eye Peninsula at Garrabost. This clay rests in places upon boulder-clay, and at one time another mass of boulder-clay, since removed, was observed to abut against the shelly deposit. These several accumulations, therefore, would appear to be comparable to those so well exposed in the sea-cliffs at the Butt.

The glacial deposits at the north end of Lewis appear to stretch across the island from shore to shore, a distance of two miles or thereabout, forming a narrow belt of low

[1] See *ante*. p. 82.
[2] *Quart. Journ. Geol. Soc.* vol. xxix. p. 532 ; vol. xxxiv. p. 819.

ground, which does not rise more than 90 feet or so above the sea. The beds extend for somewhat less than a mile along the east coast, but on the west side of the island one can trace them for a distance of three miles. They die off against the underlying rocks to the north, and disappear to the south under peat.

Having given these additional details, only a few words are needed to show what appears to have been the succession of events in Lewis, so far as these are chronicled in the glacial deposits.

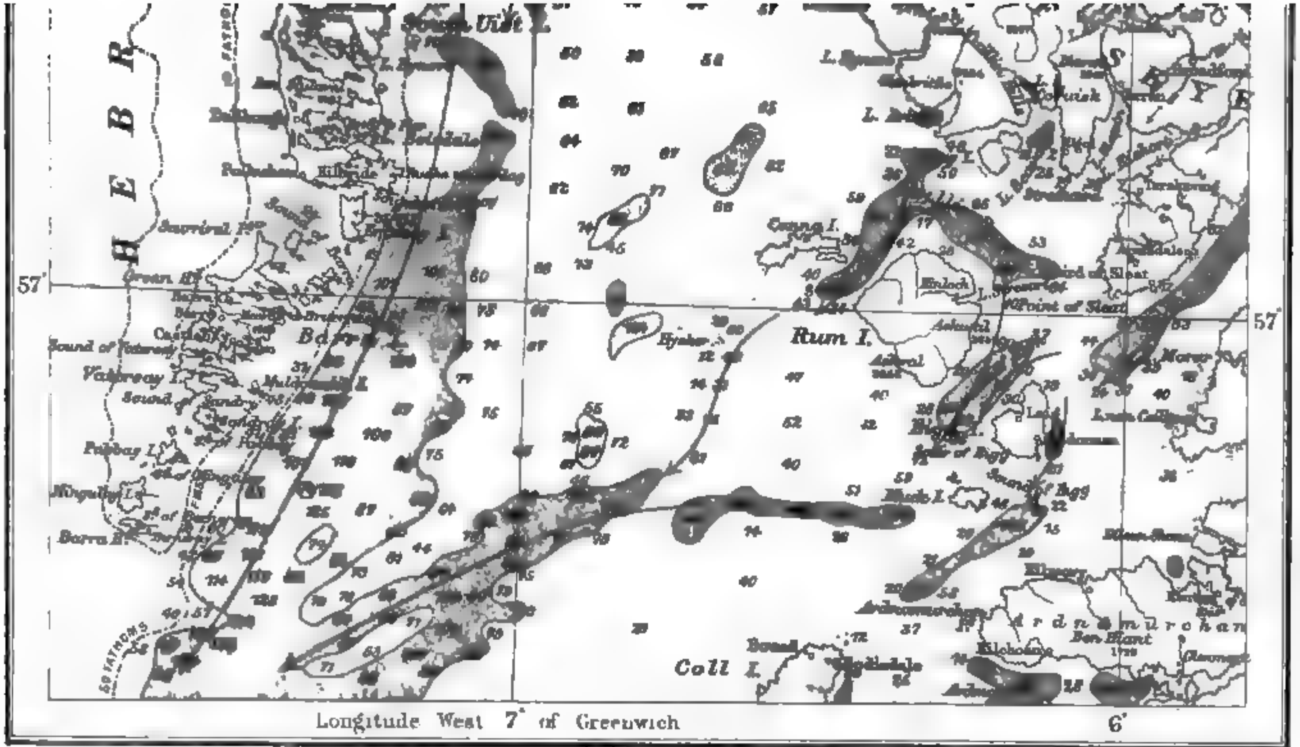
First, then, we have, as in previous cases, evidence of an epoch of intense glaciation, when, as already mentioned, the *mer de glace*, flowing out from the mainland of north-west Scotland, attained so great a thickness, that its upper strata were enabled to overwhelm the Outer Hebrides to a depth of 1,500 or 1,600 ft.

It is at first sight difficult to conceive how such a vast mass of ice could have been generated in this region. But we must remember that the greatest rainfall in Scotland is met with on the west coast, and that under glacial conditions snow would simply take the place of rain. Moreover, the Outer Hebrides would act much in the same way as the Scandinavian ice, and tend to block up the ice-flow, the egress of which would be further impeded by the great sheet that overflowed Caithness, and the Orkney and Shetland Islands in a north-west direction. For I believe it will eventually be found that the Caithness ice, as it swept out over the bed of the Atlantic, and was joined by the great glaciers that poured northwards from the rugged glens of Sutherland, overflowed the little islets of North Rona and North Barra, lying rather more than forty miles to the north of the Butt of Lewis.[1]

[1] I have not visited North Rona, but a quaint story, which I heard from an old man in Lewis, leads me to think that *roches moutonnées* and striated rock-faces must be very conspicuous there. Once upon a time there lived a saintly priest at the Ness, in the north of Lewis, who strove very hard to make the naughty folk in that neighbourhood good men and women. But somehow he didn't succeed: and at last, wearying of his task, he went to the rocks at the Butt and prayed heaven to deliver him from Ness, and its naughty people. And so it came to pass that even while he prayed, a crowd of seals bobbed up their heads at his feet, and seemed to invite him to go with them. The good man consented, and they floated him far away to the island of North Rona. Now whether it was that the rocks of that island were unusually steep and slippery, or that the holy man was just as heavy in body as in mind, will never

The fact that shelly tills, and boulders not of local origin, are all confined to the low-lying part of Lewis is very suggestive. From the manner in which the Outer Hebrides have been traversed by ice coming from the mainland, one might have expected to meet with many foreign erratics commingled with the local materials of the till, throughout the whole extent of the islands. But a glance at the map (Plate IV.) will show that this island-chain rises very abruptly from a depth that varies between 400 and 700 ft. From the south of Lewis to Barra Head the islands generally present their steepest faces to the Minch—the coastal heights often rising to 1,500 ft., and even in some places to nearly 2,000 ft. above the sea. Several of the islands, such as North Uist and Benbecula, however, form low-lying undulating plains. Now, it is obviously impossible that the lower strata of the *mer de glace* that flowed into the Minch could surmount this great wall of rock. They would necessarily be deflected to right and left, and compelled to act the part of under-currents—one flowing along the bottom of the Minch towards the north-east, and the other towards the south-west, as shown by the large red arrows on the map. Such being their course, it is evident that their bottom-moraines would be dragged and pushed along the bottom of the Minch, and would thus never invade the Outer Hebrides, save where the land was sufficiently low. If the reader consults the map, he will observe that the sea-bottom, north of Eye Peninsula, rises with a gentle gradient to the coast of Lewis. When the north-east under-current, therefore, approached the Eye Peninsula it would be enabled gradually to creep away from the sea-floor, and, meeting with less and less obstruction as it flowed, would trend more and more to the west until it fairly crossed the low grounds of Lewis, after which the whole body of the ice-sheet would proceed in one and the same direction. Thus the presence of the shelly till and foreign erratics in the low grounds of Lewis is readily

be known ; but, anyhow, the seals had hard work in getting their freight landed. They clawed and scratched, and scratched and clawed the rocks, but slid back into the water again and again, until after a supreme effort the gasping father was rolled safely ashore. 'Now,' said my friend, 'whether that story is true all through or no I will not presume to say ; but if you go to North Rona, there you will see the rocks on the shore all polished and smoothed, and much marked with long deep scratches.'



Scale of English Miles

London Edward Stanford. 26 & 27, Cockspur St. Charing Cross. S.W.

London, Stanford's Geog^l. Estab^t.

accounted for. They have been laid down by an ice-stream advancing from the bed of the sea; while the unfossiliferous boulder-clay of the rest of the Outer Hebrides is the product of the upper portion of the *mer de glace*, which of course had no bottom-moraine when it commenced to overflow the islands.

After this epoch of general glaciation milder conditions ensued and the great ice-sheet melted away, but to what extent the evidence does not say. All we know is that the ice-sheet disappeared from the Minch, which was again occupied by the sea—tenanted at that time by an arctic and boreal fauna, indicating colder waters than now lave the coasts of northern Scotland. The presence of the marine clays upon the low grounds of Lewis shows us that the land was more depressed than at present. But the amount of the submergence can only be conjectured. I met with a patch of shelly clay at a height of 175 ft. over the sea, and subsequently Mr. David Robertson obtained marine foraminifera, ostracods, and star-fish plates from a gravelly deposit in Lewis between Stornoway and Barvas, at an elevation of between 300 and 400 ft. These organic remains, Mr. Robertson thought, were probably derived from an underlying bed of clay. The clay-bed, however, was not seen, and it is impossible therefore to say whether the remains in question indicate a submergence as great as 300 or 400 ft.

How long these interglacial marine conditions endured we cannot tell. There is evidence, however, to show that the land after a time emerged to some extent so as to allow waves and tidal currents to denude and re-arrange the shelly silts and clays which had gathered in the interval over the submerged low grounds of Lewis—for the beds in question are overlaid in the north of the island by coarse gravel, shingle, and sand.[1]

Eventually extreme arctic conditions returned. Again the Minch was occupied by glacier-ice which overflowed the Outer Hebrides as before. During this second invasion of the ice the shell-beds were ploughed into, crumpled, confused,

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and worked up into the bottom-moraine. Doubtless many records of the interglacial submergence were removed by the ice, which seems to have attained a thickness rivalling that of the preceding glacial epoch. It is quite possible, I think, that the marine organisms obtained by Mr. Robertson may indicate an interglacial submergence to the extent of 300 or 400 feet, but on the other hand the deposits in which they occur may be *remaniés*. They may well have been dragged forward by the ice from a lower level.

The ice-sheet next finally retired from this region and its *moraine profonde*, and the older glacial and interglacial deposits were subjected to denudation, and here and there sand and gravel, containing broken and rolled shells of recent littoral species, were spread over their surface—thus showing that after the final disappearance of the ice (but how long after we cannot say) the island was submerged to a depth of not less than sixty feet, or thereabout. When this submergence took place the temperature of the neighbouring sea was probably much the same as it is now.

CHAPTER XIII.

INTERGLACIAL DEPOSITS AND SHELLY TILL OF SCOTLAND.—RÉSUMÉ OF RESULTS.

Correlation of interglacial fresh-water and marine deposits—Shelly tills belong mostly to later stages of glacial period—Probable condition of Scotland during the formation of glacial and interglacial deposits.

HAVING now passed in review the evidence supplied by the marine deposits that occur either intercalated with or subjacent to the till, we must next endeavour to sum up the main results obtained.

We have seen, then, that the evidence not only does not contradict but really confirms the conclusions to which an examination of the intercalated and subjacent fresh-water beds appeared to lead us. The accumulation of till or boulder-clay was not continuous all over Scotland throughout the glacial period. There was a time when the ice, which had extended from the mainland across the adjacent seas to the outlying islands, eventually melted away so far as to allow the sea to stretch into the interior of Scotland. Such a recession of the ice-sheet could only have been due to an amelioration of climate. A mere submergence of the land could not have brought about so great a change. The ice that covered the low grounds of Scotland, during the formation of the lower till, approached certainly 3,000 ft. in thickness, and it was even deeper than this between the mainland and the Outer Hebrides. But in order to float off such a great thickness of ice we should be compelled to admit a submergence of the land sufficient to drown all the lowlands and no inconsiderable portion of the high grounds also. There is no evidence, however, of any such deep submergence having accompanied or followed the disappearance of the great *mer de glace*. The highest marine deposits of

interglacial age do not attain an elevation of 600 feet. Had the submergence been much greater we might have expected some of the shell-beds of the low grounds to indicate deep-water conditions, while patches of shelly beds might now and again have been preserved at higher elevations, or some trace of their former existence might have appeared here and there in the upper till. But the shelly boulder-clays, as we have seen, are confined to low-lying maritime districts. We have positive evidence, however, that the presence of marine deposits between the morainic accumulations of two glacial epochs is really indicative of climatic changes. The succession of deposits met with in the Kilmaurs district proves that a great ice-sheet melted away from the low grounds without the intervention of the sea, leaving behind it a bottom-moraine which by-and-by supported terrestrial vegetation and was occupied by mammoths and reindeer. Here we have proof, in short, that the ice disappeared and exposed not a sea-bottom but a land-surface. The presence of the marine shells in the deposits referred to shows, however, that the land occupied by the mammoth and the reindeer subsequently became submerged before the later ice-sheet overflowed Ayrshire.

But it may be asked why the intercalated shell-beds, if they really mark mild interglacial periods, do not more frequently contain an assemblage of fossils betokening milder conditions of temperature than boreal and arctic. I have already remarked, with regard to the fresh-water interglacial deposits, that, if Scotland, during the milder intervals of the Ice Age, ever experienced a really warm climate, we could yet hardly hope to meet with any abundant or decided proof of such genial conditions. For a mild period of that kind must have been gradually succeeded by arctic conditions; and, consequently, deposits laid down during the former stage would be afterwards subjected to excessive denudation; first, by rivers and other subaërial forces, and lastly, by glaciers. We have also to remember that the land, during the invasion of the sea, would be still further acted upon, and loose fresh-water accumulations would often be obliterated. In short, if we only give the question a little consideration, we must perceive that of all interglacial deposits, those betokening

cold-temperate conditions would stand the best chance of preservation. The foregoing remarks, which appeared in the earlier editions of this work, have been justified by what we have since learned as to the temperate character of the climate which prevailed, when the interglacial beds of Hailes, Redhall, and Cowdon Glen were being accumulated.

The occurrence of interglacial marine beds shows us that the glacial period was characterised now and again by considerable submergence of the land. How many submergences there may have been, we cannot at present, and, perhaps, never may be able to say. That many of the interglacial shell-beds referred to in previous pages may be contemporaneous is quite possible, nay, even most probable. But there is nothing sufficiently distinctive in the deposits to justify us in attempting to correlate them. Some, indeed, have evidently been accumulated in deeper water than others, and it is quite clear that all the deposits cannot be strictly contemporaneous.

And if the difficulty of correlating the various marine interglacial beds be great, or even insuperable, we do not find it any easier to dovetail these with the interglacial deposits of fresh-water origin, or even to correlate the latter with each other. The evidence points to there having been great changes of climate, and that is about all we can say. Nevertheless, we may be allowed to suspect that most, if not all, of the Scottish deposits, as well marine as fresh-water, which occur intercalated between a lower and an upper boulder-clay, belong to the interglacial interval that preceded the advent of the last general *mer de glace* in the Lowlands.

One may note in many cases that the till which overlies interglacial deposits is not infrequently a somewhat looser clay than the generally excessively tough lower till that clings to the rocks underneath. Often, too, the stones and boulders of the overlying till are, as a whole, less well smoothed and striated than those in the boulder-clay below. Too much stress, however, may easily be laid upon these facts, for the nature of the till depends very largely upon the character of the débris out of which it has been formed. But even after making all due allowance for this, one cannot help being struck with the fact that the upper or overlying

boulder-clay should so often differ from the under till; for, when two beds of boulder-clay occur in one and the same section, the lower almost invariably proves the tougher of the two (see Fig. 45), and its included stones very frequently show stronger marks of glaciation than the somewhat more angular and less polished stones and boulders of the upper. Moreover, in not a few instances, one can be pretty sure that the upper boulder-clay above an interglacial bed does really belong to the last great extension of an ice-sheet over the Lowlands, and therefore he may reasonably infer that in such a case the interglacial deposits most probably belong to the mild interval that preceded the advent of that *mer de glace*. I have no doubt, for example, after having carefully surveyed the superficial deposits of the valley of the Irvine and the

Fig. 45.—Upper and lower till or boulder-clay; River Stinchar.
t, lower till, unstratified; *g*, upper till, indistinctly bedded; contains gravel, sand, and laminated clay at ×.

adjacent regions, that the till at Woodhill Quarry was laid down as ground-moraine at the time of the last incursion of the great ice-sheet upon the Lowlands, and that therefore the deposits of that place give us a glimpse of the conditions that obtained in Scotland during the earliest recognised interglacial epoch of that country. And these, as it will be remembered, were—first, a land-surface, followed in the next place by submergence.

In the present state of the evidence, it appears most reasonable to hold that the shelly tills described in preceding pages, as far as these have yet been studied, belong to the epoch of the last general *mer de glace*. They show that the latest ice-sheet that enveloped the whole mainland had to make its way in places over heaps of silt, mud, and sand, which had accumulated during the preceding interglacial

phase. We have seen how this conclusion is borne out by an examination of the shelly tills of Caithness, the borders of the Moray Firth, Aberdeenshire, and Lewis. The shelly tills of Wigtownshire, and, as I now believe, those of Berwick and South Ayrshire, have had a similar origin, and probably belong to the same date. It must not be forgotten, however, that the lower shelly till of Lewis pertains to an earlier epoch of glaciation.

We have now seen, as the result of an examination of the stratified deposits that occur underneath or are intercalcated with the till or boulder-clay, that the glacial period was interrupted at least once by an epoch of milder conditions, at the climax of which Scotland enjoyed a climate not less temperate than the present. Such a great change could not have supervened suddenly. Cold arctic conditions would only slowly disappear; long after the ice-sheet had vanished from the Lowlands, large snowfields and glaciers would linger on in the mountain regions. The flora and fauna of Scotland in the earlier stages of the interglacial epoch would therefore be such as we now meet with in cold-temperate and boreal lands. And after that epoch had reached its culmination, and plants and animals of temperate habitats had clothed and peopled the land—these would be gradually replaced by northern and arctic-alpine forms as the succeeding glacial epoch approached. Hence it is that the interrupted and patchy interglacial deposits sometimes indicate boreal and cold-temperate conditions, while in other places they yield evidences of a genial temperate climate. They are, in short, very fragmentary relics. Incomplete and imperfect as they are, however, they nevertheless enable us to form a more or less vivid picture of Scotland during interglacial times. We see the Lowlands at first clothed with an arctic-alpine vegetation and roamed over by the reindeer. Eventually pines and birches make their appearance, while the mammoth becomes a denizen of the land. As the climate continues to improve, the flora assumes a more and more temperate aspect—and the region is visited by herds of oxen and troops of deer and horses. Pools and lakelets swarm with animal and vegetable life—thickets of hazel, alder, and willow grow along the watercourses, and forests

of oak and pine flourish in drier places. Eventually, however, these genial conditions begin to wane—the climate gradually deteriorates, and snow-fields and glaciers reappear in the mountain districts. At the same time submergence of the land ensues, and eventually an arctic marine fauna occupies the Scottish seas. To what extent this submergence reached we cannot tell, but it appears to have continued until the land was drowned to a depth of 500 ft. or more below its present level.

It is uncertain, however, whether all the maritime districts of Scotland were submerged to the same degree. Thick stratified beds, containing shells and shell-fragments, and spreading over considerable areas, occur between the upper and lower boulder-clays of the north-east of Scotland up to heights of 350 or 400 ft., or even of 560 ft., according to Mr. Jamieson.[1] Higher than this no evidence of submergence has been obtained. And there is always a doubt as to whether the shells in such sands may not in some cases be of derivative origin—washed out of some pre-existing shelly boulder-clay. Mr. Horne informs me that after he had mapped the glacial deposits over a wide region in the maritime districts of Moray, Elgin, and Nairn, he thought the deposits in question were most probably of marine origin. So far, then, as the evidence goes [2] we may reasonably infer that during interglacial times Scotland experienced a submergence of 500 ft. or thereabout. The character of the shells in certain of the interglacial beds indicates arctic conditions, but it is worthy of note that such is not generally the case. Thus the facies of the fauna of the shelly till of

[1] *Quart. Journ. Geol. Soc.* vol. xxxviii. p. 172.

[2] The evidence of an interglacial depression does not rest upon that of fossiliferous sands, &c., alone. At several places on the coast we find shelves cut in the rock slopes which are clearly not of postglacial age. The old beach-lines referred to are often very faintly marked – for the ground has been glaciated since the shelves were cut out. Thus it is sometimes difficult to perceive them when we are actually standing upon them, but when we retire to some little distance, so as to catch the profile of the land, they are then seen to form prominent platforms and notches. Some admirable examples occur on the high grounds that face the sea at the mouth of the River Stinchar in South Ayrshire ; others are noticeable on the shores of Fife, as near Elie and Newport. A well-marked terrace near Ballantrae (Stinchar) is distinctly ice-worn, and shows here and there patches of till with striated stones resting in hollows upon its surface. It is 250 feet above sea-level. That old rock-terrace, therefore, is either of preglacial or interglacial age—most probably the latter.

Caithness is not particularly arctic, but indicates rather cold-temperate conditions. This shows us that before the advent of the last general *mer de glace* the North Sea was occupied by a fauna not unlike that of the present. The arctic character of certain other shelly deposits, occupying the same general horizon (*e.g.* at Tangy Glen), would seem to indicate, however, that while the submergence continued colder climatic conditions supervened, and this we may infer took place before the land became entirely swathed in snow and ice. Of the plants and animals that may have clothed and peopled Scotland just before the advent of the second great *mer de glace* we know very little. The country was probably as desolate then as North Greenland and Spitzbergen are now. Eventually the whole region was again drowned in ice—which streaming out in all directions usurped the bed of the shallow seas and overflowed the Inner and Outer Hebrides on its way to the Atlantic. In the basin of the North Sea the Scottish ice-sheet united with that advancing from Norway, and Orkney and Shetland were again overwhelmed. So far as Northern Scotland was concerned, this second *mer de glace* was hardly, if at all, less extensive than that underneath which the lower boulder-clay was accumulated.

CHAPTER XIV.

DEPOSITS OVERLYING THE TILL OF SCOTLAND.

Åsar—theories of their origin; Hummel's and Holst's views—High-level terraces of gravel, &c. at Eaglesham—Ridges and mounds of gravel, &c.—Action of torrential waters flowing between margin of ice-sheet and hill-slopes.

WE must now consider the deposits that overlie the upper or youngest boulder-clay of the Lowlands. They consist, as will be seen presently, of very diverse materials, and the mode of their formation has long been a fruitful source of controversy. It is a matter of no little moment, as the sequel will show, that we should ascertain the sequence of events that followed upon the decay of the latest general *mer de glace*; and this we can only do by taking the evidence in some little detail. I shall therefore first describe the more typical deposits and indicate the mode of their origin, and then shall place the evidence together so as to bring out what seem to me to be the leading features in the history of late glacial times.

Among the most notable of the accumulations that overlie the upper till of the Lowlands are certain ridges and long mounds which often form conspicuous features in the broader valleys running for miles like great artificial ridges across the country. They usually rise more or less abruptly above the general level of the ground to heights of 20 or 30 or even of 50 or 60 ft., with a breadth at the base of 100 to 400 or 500 ft. The sides of the more sharply-crested ridges often slope at angles of 30° or 35°, while the broader topped banks are not so steep. Ridges and mounds alike run in long gently sinuous, and now and again more rapidly curving lines, following in their direction the trend of the valleys in which they occur. They rest either on boulder-clay or solid rock,

and it is particularly worthy of note that the gravel and sand of which they are composed are strictly confined to the ridges and mounds; that is to say, these deposits do not spread out laterally upon the adjacent low ground. Thus it frequently happens that in wide lowland regions the only water-worn accumulations of glacial age to be met with are those of the solitary mound or ridge that runs like a tortuous embankment athwart broad stretches of boulder-clay and bare rock. The steeper ridges are composed chiefly of gravel, generally coarse, and showing little or no trace of bedding. Indeed, in many places they consist of tumultuous heaps of coarse gravel, shingle, and water-worn boulders; or, as the case may be, of an agglomeration of large blocks and angular and subangular débris mixed with earthy grit and sand. The abrupt embankments, on the other hand, are usually built up of finer gravel and sand, which are often beautifully bedded. Similar ridges (known as *åsar*, pronounced *osar*), are grandly developed in Sweden, and I shall, therefore, adopt the Swedish name for ours. Amongst the best examples of Scottish åsar are those of the Lothians, and the lower reaches of Tweeddale and Nithsdale.

All geologists admit that the åsar are, in the main, water-formed accumulations, but their mode of formation has long been matter of discussion. At one time they were believed to be of marine origin—to have been heaped up by tidal currents. This view, however, has been abandoned. We know now that they have been built up by water flowing down the valleys; not, however, by ordinary river-action. Banks of gravel and sand no doubt accumulate in the beds of rivers, but if the rivers were to disappear such banks would not form prominent ridges rising abruptly above the general level of the surrounding land. They would, moreover, coincide throughout their course with the lowest level of the valley. But our åsar, although they trend with the general inclination of the land, do not slavishly follow the line of lowest level. Usually, indeed, they show a certain independence of the minor features of the ground—sometimes winding along one side of a valley—sometimes along the other. Occasionally they suddenly terminate, and after a longer or shorter

interval they may begin again as abruptly—or they may die off once for all.

It is now believed that these remarkable åsar are of fluvio-glacial origin—formed by torrents and streams flowing either upon or underneath the *mer de glace*. Their subglacial origin was advocated a number of years ago by Mr. D. Hummel[1] of the Geological Survey of Sweden, but more recently Dr. Holst has formulated the view that the åsar have been accumulated in the beds of supra-glacial rivers.[2] This theory, which some glacialists think explains the phenomena more satisfactorily than Hummel's, is nevertheless not without its difficulties. It is quite possible, indeed, that both infra- and supra-glacial torrents and streams existed during the melting of the *mer de glace*, just as we know is the case in Greenland. Among the phenomena which Hummel specifies as peculiarly suggestive of the origin of åsar, are the frequent passage of the gravel into true morainic matter (a passage which may be traced not only along the sides of an ås, but also in the direction of its trend); the appearance of large and small angular fragments of rock in the heart of well water-worn gravel; the less rounded aspect of the stones in the upper part of an ås; the existence of water-worn materials underneath true bottom-moraine; the confused and dislocated or jumbled aspect of the bedding sometimes seen in the interior of an ås; the general agreement that obtains between the trend of the rock striations and the direction followed by the åsar; and finally, the entire absence of fossil organic remains. These facts seemed to Hummel to indicate fluvio-glacial action, and he concluded that the åsar had been formed in tunnels underneath the ice by running water (introduced through crevasses &c.) working upon the bottom-moraines of the *mer de glace*. This ice-flow necessarily followed the average slope of the ground, and in like manner the trend of the subglacial waters would be determined by the contour of the underlying land-surface. Hence åsar and rock-striæ would coincide in general direction. Now and again, however, the subglacial waters, controlled by variations in the direction of the slope down

[1] *Bihang till K. Svenska Vet.-Akad. Handlingar*, 1874.

[2] *Geologiska Föreningens i Stockholm Förhandlingar*, Bd. iii. No. 3, 1876. See also an account of Holst's observations in Greenland: *Sveriges Geol. Undersök. Afhandl. och Upps.* 1886.

which they flowed, would be compelled to diverge to some extent from the course pursued by the *mer de glace*, which, independent of such minor irregularities, followed only the general or average slope of the ground. This theory seems to account satisfactorily for the passage of the ås-gravels into morainic matter, and for the fact that the gravels in the upper part of an ås are often not well rounded. It likewise explains the occasional occurrence of angular blocks in the interior of an ås, for such blocks might have been introduced through crevasses or melted out of the ice itself, and so have dropped from the roof or sides of the subglacial tunnel upon the bed of the stream. The confused and jumbled stratification sometimes characterising the deposits in the heart of an ås might be accounted for by occasional collapse of the tunnel, or by the final settling down of the accumulations when the whole process of their formation had ceased.

Hummel's theory is in accord with so many of the phenomena that it must to some extent be true. There can be no doubt, for example, that the åsar are in some way connected in their origin with the great ice-sheet. Dr. Holst therefore accepts Hummel's main contention. He thinks, however, that the ås-rivers flowed *upon* and not *underneath* the *mer de glace*. During the melting of the ice-sheet numerous rivers, it is conceived, would flow over its surface, following of course the general direction of the ice itself. These rivers would be small or large, according as the water-divides were near each other or widely separated. Such conditions would necessarily obtain in the highest degree in regions where the *mer de glace* flowed across broad lowland tracts towards its termination. Over such regions there would be a general absence of crevasses, and the superficial waters would thus have free course. Let us then picture to ourselves a series of broader and narrower ice-valleys radiating outwards to the terminal front of the *mer de glace*. At the bottom of each of these flows a stream or river. The ice over and through which the rivers flow melts more rapidly than that of the valley-slopes, so that eventually river-troughs more or less deep are licked out in the ice-sheet. But, as the ice melts, the morainic matter contained in it is released and tends to find its way from all the valley-slopes into the

streams, the bottoms of which become in this way paved with sand, grit, and rock-débris. This material, carried forward by the tumultuous waters, suffers more or less attrition, and sand and gravel are formed. Some of the larger blocks, however, and now and again much angular débris, might come to rest and be eventually buried underneath better water-worn detritus. Thus layer after layer accumulates in the beds of the rivers as the ice-sheet melts, until finally the ice disappears, and the old river-courses then show themselves as ridges rising prominently above the surrounding low ground.

This theory, suggestive though it be, is yet not free from objection. It might be pointed out, in the first place, that Dr. Nansen found no superficial rivers or streams in the interior of Greenland. But this can hardly be urged against Dr. Holst's view, since we have no reason to believe that the inland ice of Greenland is in a state of decadence. Moreover, in summer-time, as we know, the marginal area of that inland ice is actually traversed by superficial streams, and it is therefore quite conceivable that similar streams and rivers may have flowed upon the surface of our own *mer de glace* during the later stages of a glacial epoch. But it may be further objected that we have no grounds for supposing that the old European ice-sheets would be charged with included morainic matter to a greater extent than the *mer de glace* of Arctic and Antarctic regions. Everyone who has visited Greenland bears testimony to the remarkable freedom of the inland ice from included morainic matter. When 'dirt' and stones are met with in the ice they are usually noted on account of their infrequency. Dr. Holst, who has himself studied the glacial phenomena of Greenland, has indeed described the occurrence of very considerable superficial moraines, but we must remember that these have been derived from nunatakkr and the exposed rock-surfaces overlooking the marginal areas of the inland ice. There is another kind of moraine, however, called by Dr. Holst the 'inner moraine,' which is included in the mass of the ice itself. The materials of this moraine are characterised by their angular form, and have been derived, according to him, from the higher rock-ledges overflowed by the ice. They

have been detached, in short, from the upper parts of ice-drowned mountains and cliffs, and travel forward embedded in the mass of the *mer de glace*. By-and-by, as the ice melts the débris gradually appears at the surface, where it forms a superficial moraine. This intraglacial moraine Holst carefully distinguishes from the true bottom-moraine, which is not disseminated through the ice, but is disclosed to view in arches or tunnels under the ice-front, where it presents all the aspects of a normal boulder-clay, consisting as it does of blunted and scratched boulders embedded in bluish clay. Now and again, the same author tells us, some of this material is commingled with intraglacial débris, and in one place he found the superficial detritus along the borders of the inland ice was composed mainly of bottom-moraine—which had been forced to the surface owing to the form of the ground underneath the ice.[1]

It is thus conceivable that our *mer de glace*, as it made its way from the mountainous regions of the interior outwards across the lowlands, should contain at various levels rock-fragments derived from the upper portions of cliffs and from the tops and sides of more or less isolated and prominent hills and mountains. Moreover, during the melting stage, loose débris would be showered in increasing abundance upon the *mer de glace* as mountain-summit and hill-top successively reappeared. It may be admitted, therefore, that the old *mer de glace* may well have provided sufficient 'inner-moraine' and superficial débris to supply the surface-rivers with materials to fill their beds. But another difficulty presents itself. As the materials continued to be dissolved out of the ice and to find their way down the slopes of the ice-valleys into the rivers, the bottoms of those valleys and the beds of the streams themselves would come

[1] Some geologists have pictured to themselves a constant travelling upwards of the bottom-moraine into the mass of the ice, and have imagined that in this way the ancient *mers de glace*, as they flowed on their way, must have been more or less abundantly charged with subglacial detritus. But this notion is contradicted by all that is known of modern glacial action. The glaciers of Greenland, like those of the Alps, show included 'dirt-bands,' but these consist of dust and grit blown by the wind upon the surface of the ice, and subsequently buried under new falls of snow. The bottom-moraine, as Drygalski remarks, travels persistently under the ice towards the ice-front, and is not carried up into the ice, so as to form included layers. (*Grönlands Gletscher und Inlandeis*, p. 50.)

to be protected from ablation. The ice of the water-divides and upper slopes of the valleys would by-and-by melt away more rapidly than those portions of the *mer de glace* which were deeply buried under rock-débris. Thus in time the configuration of the surface would be so altered that the rivers would be compelled to desert their gravel-beds, which by-and-by would themselves be converted into water-divides, while the sites of the former divides would be occupied by newer watercourses. In short, the tendency of the superficial water-flow would be rather to distribute morainic material in irregular sheets over the surface of the ice than to arrange it in determinate linear courses. Unless, indeed, we are to suppose that the superficial rivers succeeded in rapidly cutting their way down to the bottom of the ice-sheet, and thus at an early period formed deep trenches into which was shot all the rock-rubbish derived from the ice during its dissolution. If it be hard to conceive such conditions possible, it is not easier to see how river-beds filled with detritus to a depth of 50 to 60 ft., more or less, could retain their position and sink gradually down during the general ablation of the ice-sheet. One can more readily understand how a subglacial water-drainage would tend to be preserved, especially at a time when the *mer de glace* was decaying, for the ice overlying the lowlands would then be sluggish and even inert, and the watercourses that tunnelled it would thus be less liable to disturbance by its movements.

So far as the Scottish åsar are concerned, Hummel's theory seems to explain the phenomena more satisfactorily than the other. But, as I shall show presently, there are certain accumulations of gravel and sand which can only be explained by the action of the superficial drainage of the *mer de glace*.

In some hilly districts of Scotland we find the slopes of the ground fringed, at uniform levels, with shelves and terraces of sand and gravel. These generally dip outwards and downwards, with a gentle inclination from the high grounds against which they abut. Occasionally, several such platforms occur in succession, and, when seen in profile, resemble giant staircases. The deposits of which

they are composed are usually more or less well bedded, and consist of gravel and sand, with which clay is sometimes intermingled. The deposits, however, are not always well water-worn; sometimes, indeed, they consist of only angular or subangular stones, and a kind of earth or earthy sand and clay. None of them has yielded any organic remains.

A very fine example of the phenomena described occurs at Enoch, near the village of Eaglesham, about twelve miles south-west from Glasgow. In the accompanying section (Fig. 46), the general outline of this series of terraces is shown; *t* represents the till, *s* the sand and gravel, and the figures indicate the height in feet above the sea-level.

Fig. 46.—High-level terraces of gravel and sand at Eaglesham.

Anyone may see that these shelves are old water-levels, and that when the upper terrace was being formed water must have washed the slopes of the Dunlop and Strath-avon Hills at a height of 800 ft. above the present sea-level. By referring to the map (Plate III. p. 121), the reader will observe that the hills, upon the slopes of which the terraces occur, form the watershed between a number of feeders of the River Clyde flowing towards the north, and certain streams that go south to join the rivers Garnock and Irvine. Towards the east the hills fall away into the vale of the River Avon, which unites with the Clyde near Hamilton. The terraces, as I have said, skirt the open hill-side; they do not lie in any deep valley, neither is there any spacious mountain-glen from which we might suppose some massive ice-flow to have protruded and dammed up a stream so as to form a glacial lake. Standing on the terraces themselves we find ourselves overlooking the broad vale of the Clyde, with no higher ground than our own between us and the Campsie Fells. Here,

if anywhere, we seem to have relics of old sea-beaches. They contain not a single trace of any marine organism, however, and the deposits themselves do not strike one as being characteristically littoral; in some places indeed they consist rather of an earthy angular débris than gravel. Yet how otherwise can we account for them? Surely the water that spread them out along the slopes behind Eaglesham must have stretched away north for sixteen miles at least, until it abutted against the Kilpatrick Hills and the Campsie Fells? It is not necessary, however, to suppose that the water extended so far.

Let me point out some of the phenomena that would present themselves during the dissolution of a great ice-sheet. As the surface of the *mer de glace* became lowered, the higher hills of the lowland districts would begin to appear. Among such hilly tracts that broad ridge of high ground that extends along the county-boundaries of Renfrew, Ayr, and Lanark is one of the most conspicuous, for it reaches in places to a height of more than 1,230 ft. above the sea. The time must have come, then, when the *mer de glace* melted away from the higher parts of the Strathavon and Dunlop Hills until its surface had sunk to the level of 800 ft. At this period those hills would form an island in the sea of ice, from which in summer-time streams would flow north and south just as they do now. But as the heavy snows that had gathered over the hills and moors in winter-time would melt during summer, it is evident that large bodies of water would then descend to the margin of the *mer de glace*. In Norway and the Alps the glaciers melt away in summer to some extent from the valley-slopes, and it is often possible for one to penetrate for some little distance below the ice, which seems to shrink as it were from contact with the heated rocks. Between the mountain-slope and the frequently overhanging sides of the melting glacier torrents of water often make their way over a rough bottom of rocky débris, gravel, and boulders. Now, as Mr. Jamieson has shown,[1] something like this, only on a larger scale, must have taken place in Scotland during the

[1] *Quart. Jour. Geol. Soc.* 1874, p. 329.

melting of an ice-sheet. The margin of the *mer de glace* would retreat, as it were, for some distance from the slopes of the Dunlop and Strathavon Hills, while a torrent, derived partly from the thawing snow of the hills and partly from the melting of the ice-sheet itself, would rush along the broad trench formed between the slopes of the hills and the edge of the great glacier. Here and there, where the hill-slopes retired so far as to form a broad bay, the water would spread itself over a wider area, and the débris and gravel and sand which it hurried along would in such places be distributed more or less evenly over the bottom. But in places where the whole space between the margin of the ice-sheet and the hills was coursed over by a tumultuous rush of waters, it is clear that the detritus could not be so evenly spread out, but would be heaped up in irregular mounds and ridges, whose trend would coincide in direction with the flow of the water.

Such are the results one would naturally expect to follow from the melting of the ice-sheet in a hilly region like that under review. And the appearances now visible certainly seem to tally very closely with the conditions inferred. The terraces of gravel described above occupy an embayed recess of the hills, and passing eastwards from them at about the same elevation (nearly 800 ft.) we follow the spoor of the old torrents in a remarkable series of ridges, mounds, hummocks, and flats of gravel, with occasional patches of sand, which lead us along the face of the hills at a gradually decreasing elevation by Clachearn, Cladance, and Chapelton, into the vale of Strathavon. The lower two terraces mark the successive lowering of the old lake or bay by the melting of the ice barrier; it is quite possible, however, that this may have been suddenly effected by the instantaneous giving way of some part of the glacier and the opening of a readier outlet for the water.

Terraces resembling those at Eaglesham have been detected in other hilly districts. I have met with some good examples in the Moorfoot Hills, at a height of 1,050 or 1,100 ft., which I believe have been formed in the same way as the gravel flats of the Dunlop and Strathavon Hills. Still farther south high-level shelves of gravel and sand were

detected by Mr. H. M. Skae, in Nithsdale, at a height of 1,250 ft. above the sea. These he agreed with me in thinking had probably been deposited in a temporary lake during the melting of the *mer de glace*, and while a massive stream of ice yet occupied the broad vale of the Nith. Similar accumulations of sand, gravel, clay, and silt have been met with at considerable elevations in the Northern Highlands.[1]

Mounds and ridges of gravel and sand may occasionally be followed up a valley to its *col*, and even across that into the drainage-area beyond. When this is the case it invariably happens that the *col* is one of the lowest in the hilly regions where it occurs. And if we reflect for a little upon what would happen in such a hilly region when the ice-sheet was melting away and becoming divided into a series of large local glaciers, we shall hardly fail to see that in those valleys whose *cols* were lowest, the glaciers would disappear more rapidly than they would in valleys that drained higher elevations and wider gathering grounds. Let us conceive, then, that torrents are sweeping forward detritus between the margins of the ice and the flanks of some slowly emerging range of hills. It is evident that the water in its course down a main glacier-valley would overflow whenever it reached a gap or *col* in the hill-range, and so make its way in some other direction. If this smaller valley happened to be still occupied with ice, then the water would probably find its way as before between the edge of the glacier and the side of the valley, so that when the ice finally disappeared, the course of the torrent would be traceable in ridges and heaps of gravel fringing the hills at some height above the valley-bottom. And these we should be able to follow more or less continuously, up to and even across the *col*, into the other drainage-areas from which the deposits were derived.

I could mention many instances in which these very appearances are visible. Thus, in the Muirkirk district Mr. B. N. Peach traced a number of gravel hillocks along the hill-slopes that overlook the head of the Greenock Water, a tributary of the river Ayr, across a narrow *col* into the valley of the Glengavel Water which joins the river

[1] *Quart. Journ. Geol. Soc.* 1874, p. 329.

Avon. The torrents that carried these deposits seem to have spread out over what is now the watershed of the river Irvine: and the evidence which I gathered during the geological survey of the district led me to believe that a large glacial lake must have existed at that place for a long time during the dissolution of the ice-sheet. In this lake considerable accumulations of gravel, sand, and clay took place; and although these are now much denuded they still form wide flats, while traces of horizontal ledges cut into the rocks, and evidently marking old water-levels, indicate successive margins of the lake as its waters were drained away. No trace of anything organic was found in the deposits.

Many years ago I pointed out that there was something peculiar in the distribution of gravel ridges and mounds in the valleys of a hilly region. In regard to the hilly district of Peeblesshire, I showed that these do not occur in all the valleys alike; some they quite choke up, while from others they are entirely absent. Nor at first sight is there anything remarkable in the valleys themselves to account for this anomaly. They may be wide or narrow, deep or shallow, winding or comparatively straight. Now this peculiar distribution of fluvio-glacial gravel and sand can be reasonably accounted for in the same way as the similar deposits in the neighbourhood of Glengavel Water. The valleys in which they extend up to the dividing *col* are just those from which the glaciers would disappear soonest, and which would, therefore, form the readiest channels of escape for the water derived from the thawing ice-sheet. The valleys that drained wider and more elevated regions would, on the other hand, long continue to be filled with glaciers, and when at last these had ceased to be confluent with those of adjoining valleys, the gravel deposits would no longer take the form of confused heaps and ridges, frequently disposed along the flanks of the valleys, but would spread out in undulating flats in the same manner as the morainic gravels that cover the bottoms of the valleys in Alpine and Arctic lands.

CHAPTER XV.

DEPOSITS OVERLYING THE TILL OF SCOTLAND—*continued.*

Kames, their general character—Passage of water-worn detritus into angular débris—Association of kames with characteristic moraines—Geographical distribution of kames; their occurrence opposite the mouths of considerable mountain-valleys—Kames of morainic and fluvio-glacial origin.

IN the preceding chapter we have considered the origin of our äsar and of other accumulations of gravel and sand which occupy what seem at first sight to be somewhat abnormal positions in certain hilly regions. The äsar of the Lowlands, as we have seen, would appear to have been formed by the action of torrential streams flowing underneath and perhaps in some cases upon or within the decaying ice-sheet. The terraces and ridges of sand and gravel that are disposed upon the flanks of hills seem, on the other hand, to have been deposited between the edges of the melting ice and the hill-slopes against which it abutted. Both sets of accumulations, therefore, belong to the period of decay of the last general *mer de glace.*

It is obvious that when the ice-sheet had so far melted away as to leave the Lowlands partially uncovered, morainic materials would begin to be spread and sprinkled over the ground. What we have now to do, therefore, is to examine the deposits that rest upon the upper boulder-clay for the purpose of tracing, if we can, the spoor of the retiring ice.

The most conspicuous of those deposits are certain great sheets and masses of distinctly water-worn materials. These occur at all levels, from the coast up to a height of more than 1,500 ft. above the sea. The most characteristic form assumed by them is that of rolling mounds, cones, and ridges, all of which consist, for the most part, of gravel and

sand. To such an extent, indeed, is this the case, that the whole group is often spoken of as the 'sand and gravel series.' It does not cover nearly so large a tract of ground as the till. In the higher mountain regions many miles of country may be traversed without discovering a single patch of sand or gravel. As a general rule, the deposits belonging to this group are confined to lowland districts, where they appear at first sight to be distributed in a most arbitrary manner. Occasionally we may follow them for miles, when all at once they will die out, and then we may not meet with them again until we have passed into quite a different district. But capricious as the distribution of the series may be, we shall yet find that this drift is arranged and grouped with a certain definite relation to the external form or contour of the country.

The sands and gravels have, as I have just said, a

Fig. 47.—Sand and gravel resting on denuded nucleus of till: railway cutting, near Douglas Mouth Bridge, Lanarkshire.

tendency to shape themselves into mounds and winding ridges, which give a hummocky and rapidly undulating outline to the ground. Indeed, so characteristic is this appearance, that by it alone we are often able to mark out the boundaries of the deposit with as much precision as we could were all the vegetation and soil stripped away and the various subsoils laid bare. It is most common to find mounds and ridges confusedly intermingled, crossing and re-crossing each other at all angles, so as to enclose deep hollows and pits between. Seen from some dominant point, such an assemblage of *kames*, as they are called, looks like a tumbled sea—the ground now swelling into long undulations, now rising suddenly into beautiful peaks and cones, and anon curving up in sharp ridges that often wheel suddenly round so as to enclose a lakelet of bright clear water. Fine examples of sand and gravel hills are seen in Lanarkshire,

at Carstairs and Carnwath. They are also well developed in Haddingtonshire, near Cockburnspath; in Berwickshire, at Dunse, and north of Greenlaw; in Roxburghshire, at Eckford; and another fine set is seen in the valley of the Tweed, at Wark and Cornhill, Northumberland. At Leslie and Markinch, in Fifeshire, a similar series occurs, and like accumulations appear more or less abundantly throughout the lowland districts.

Not infrequently the slopes of the kames are carpeted with fresh green turf, in strong contrast to the more sombre-hued vegetation of the surrounding clay-covered tracts. The local names in the country sufficiently attest this peculiarity. 'Green Hills' are of very common occurrence, and I have usually found the name restricted either to kames or to certain little projecting bosses and cones of friable, decomposing, igneous rocks. When the kames are composed of large stones, the vegetation on their slopes becomes coarse and poor, and the fresh green grass then gives place to clumps of broom or stunted gorse. This is more usually the case with the sharper ridges and peaked cones, these being made up chiefly of coarse gravel and shingle. The gentler undulations consist for the most part of fine sand and gravel, and hence, in a rough way, the slope of a kame and the character of the vegetation that clothes it serve as a kind of index to the nature of the materials lying below.

Almost all the isolated solitary mounds that I know of are made up of fine sand, and some of the best examples of these occur in Fifeshire. A small one, quite close to Dunfermline, is locally famous under the name of Mont Dieu. According to an old story, this drift-mound owes its origin to some unfortunate monks who, by way of penance, carried the sand in baskets from the sea-shore at Inverkeithing. A similar tradition accounts for a conical hill of fine sand at Linton, in the valley of the Kale Water, Roxburghshire; of this hill it is said that 'two sister nuns were compelled to pass the whole sand through a riddle or sieve as a penance for their transgressions or to obtain pardon for a crime of a brother.' [1]

[1] *History and Antiquities of Roxburghshire.* By A. Jeffrey, vol. i. p. 41.

Another mound of the same material (Norrie's Law), a few miles north from Largo, in Fifeshire, is noted as the burial-place of some great worthy of past times. Who he was does not appear, but no doubt he must have been 'a superior person,' for he was buried in a suit of silver armour, most of which, unfortunately, found its way to the melting-pot soon after its discovery by a farmer. Other isolated cones, in various parts of the country, have often been described by local antiquaries as tumuli, apparently for no other reason than that they resemble these in external appearance. It is not unlikely, however, that such cones may occasionally have been used as burial-places. It is certain, too, that some of the bolder ridges and mounds have been fortified and utilised for purposes of defence, the ditches scooped in their sides being still apparent. Protected by strong palisades of wood, and surrounded as most of them

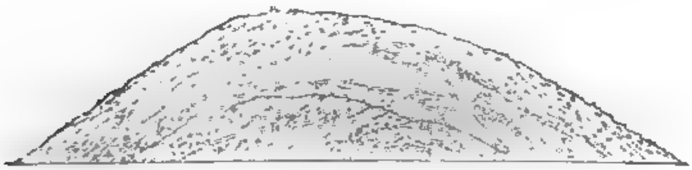


Fig. 48.—Section across kame: Douglas Railway, near Lanark.

probably were by dense forest, one can easily see how an abrupt kame or steep cone might be made a very formidable fortress in the days of spears and arrows.

The deposits of which the kames are composed are usually stratified, and, in some of the finer-grained accumulations very beautiful examples of false or diagonal bedding frequently occur (Figs. 47, 48). But in many cases the coarser heaps of shingle do not exhibit any traces of stratification, the stones being piled up in dire confusion. It is remarkable, however, that the gravel-stones, whether small or large, are almost invariably well-rounded and water-worn. To this, however, there are occasional exceptions, for sometimes the deposits are not only unstratified but earthy, and the stones are angular and subangular, some even showing faint ice-markings; and such accumulations are associated with heaps of well water-worn gravel and hummocks of sand in such a

way as to show that they all form part and parcel of the same series. At the highest elevation reached by the kames the water-worn aspect of the stones becomes, as a rule, much less conspicuous than it is at moderate elevations, say at 900 ft. above the sea, down to lower levels, and now and again it vanishes altogether, and we then have heaps of débris which are not distinguishable from ordinary morainic rubbish. Occasionally till forms the nucleus of a kame (Fig. 47), but sometimes the till has the appearance of having been intruded amongst the water-assorted deposits, the latter in this case being usually much disturbed.

Erratics do not often occur embedded in the sand and gravel, but they are met with in this position from time to time; and doubtless if our opportunities of inspecting the contents of the kames were more frequent, embedded boulders would appear more numerous. It is remarkable, however, that if they appear to be of infrequent occurrence in the interior of the kames, they are found often enough dotted over the tops and slopes of these hillocks. In some cases their appearance at the surface may be due to denudation; they may once have been embedded in the gravel and sand, and only have become exposed by the gradual washing away of the deposits in which they lay concealed. But this has certainly not always been the case. Many of the mounds and hummocks upon which these erratics rest have evidently suffered little or no denudation since the period of their formation. The shape of the heaps and ridges is undoubtedly original, and we cannot but conclude that the erratics in question were dropped upon the surface just where we see them.

Sometimes the bedding of the kames is much confused, as if, after the layers of sand, clay, and gravel had been laid down in a horizontal or nearly horizontal plane, some force had squeezed and pushed them out of place, twisting, folding, and crumpling them up; but this, as far as my experience goes, is not a common occurrence.

Associated with the sand and gravel, we here and there come upon deposits of silt and clay which have occasionally been worked for brick-making. These beds are usually finely laminated. But neither in them, nor yet in

the sand and gravel, have any organic remains been discovered.

I have said that when we trace the sand and gravel drift up to high levels we find it passing into a rude kind of angular débris like moraine-matter, and that now and again similar morainic detritus occurs closely associated with kames. This is frequently the case along the base of a mountainous or hilly region, especially opposite the mouths of valleys. Thus in the hollow traversed by the railway between Perth and Crieff we find numerous sand and gravel hummocks, heaps, ridges, and undulating flats closely associated with banks and mounds of earthy sandy débris full of large erratics, numbers of which are also sprinkled over the surface of the mounds. These, there can be no doubt, are moraines belonging to the same date as the gravel deposits that surround them. Similar appearances may be noted along the foot of the Cheviot Hills, especially where the valley of the Kale opens out upon the low grounds of the Teviot. A large moraine with associated hummocks of gravel and sand can be seen a little to the south of Eckford, and similar heaps of morainic and water-worn detritus occur at the foot of the hills near Morebattle. In many other places where the Lowlands approach the mountains the same phenomena may be studied, as along the base of the Moorfoots and the Lammermuirs, and on the low grounds at the foot of the hilly and mountainous districts in Ayrshire, Galloway, and Dumfriesshire. Even in the Western Highlands a similar commingling of sand and gravel heaps and moraine-matter may be observed, scattered over the undulating moory tracts that lie along the lower reaches of some of the sea lochs, as in the neighbourhood of Connel Ferry and Dunstaffnage. Another not uncommon feature is the association of the kames with broad flats or gently-undulating sheets of sand and silt. Thus in Strathmore, where kames are strongly developed opposite the mouths of the Highland valleys, such as those of the rivers Ericht, Isla, South Esk, &c., they are flanked by wide stretches of sand, silt, &c., which extend outwards to the base of the Sidlaw Hills. These broad flats are comparable to the 'frontal aprons' or overwash deposits, which are similarly associated with the kames of North America.

As we proceed from the low grounds into the mountain-valleys, the gravel deposits become coarser and the morainic matter assumes a more tumultuous aspect. Here we begin to meet with rude accumulations of earthy and rocky débris mixed with coarse gravel and sand, and large angular unpolished blocks. These deposits are sprinkled loosely over the mountain-slopes, but in many places they assume a more or less distinct shape, so as often to form rather striking objects in a landscape, rising as they sometimes do in the throats of rugged mountain-glens into abrupt concentric ridges and mounds—the convex faces of which invariably look down the valleys. Frequently the whole bottom of a valley is covered with these deposits over wide areas—the ground presenting a very hummocky outline. Erratics of all shapes and sizes strew the surface of the cones and mounds and ridges, and are scattered over the bare rock itself. Excellent examples of these phenomena will be found in every glen in the Highlands, but anyone who wishes to have a good idea of their general character can hardly do better than visit Strath Bran and Glen More in Ross-shire, which are now so very easy of access. Even in such mountain-valleys we shall find that the coarse moraines are often associated with heaps of sand and gravel, which not infrequently cannot be distinguished from the similar mounds that occur in the kame-areas of the Lowlands, while terraces of gravel and sand occur ever and anon fringing the valley-slopes often at considerable heights above the present streams.

The higher valleys of the Southern Uplands furnish us with similar phenomena. In Galloway we find the mountain-slopes abundantly coated with angular débris and erratics, and numerous true moraines associated with coarse gravels crowd the bottoms of the valleys that open out from the Merrick and other heights of that region. In the Peeblesshire uplands moraines are not so numerous, but well-marked ones occur at Loch Skene and in many other valleys of that region. I have noticed true moraines also at the head of certain valleys in the Cheviot Hills, but they are comparatively insignificant.

It appears to hold generally true of all the larger areas of the kame deposits that these occur in valleys at or near where

the rivers escape from the confined mountain-glens or upland dales to enter upon the broad low grounds. And not only so, but the extent of the gravel beds seems frequently, if not always, to be in direct proportion to that of the drainage-area in which these occur. When this last is very extensive the kames almost invariably attain an extreme development. On the other hand, when the river system is comparatively insignificant, so likewise are the deposits of sand and gravel that cumber the ground where the main valley begins to open out upon the Lowlands. A few examples will illustrate my meaning.

If the Ordnance Survey map (sheet 23) be examined, it will be observed that the river Clyde, after leaving the hilly country through which it flows in a general northerly direction, suddenly turns to the west, near where it is crossed by the Caledonian Railway, so as to skirt for some miles the base of the uplands from which it has just escaped. Immediately to the north of this westerly part of the river's course (in the neighbourhood of Carstairs and Carnwath) the ground rises in a very gentle incline, and undulates away to north and north-east for several miles, at a general level of one hundred feet or thereabout above the river. It is precisely here where we encounter a widespread series of kames, cones, mounds, and banks of gravel and sand. Standing among these hillocks and turning towards the south, we look right up the valley of the Clyde and into the great Southern Uplands. But the gravel deposits in this case are not restricted to the low grounds on the northern slopes of the river-valley. Considerable heaps of gravel and sand may be traced up to and even beyond Lamington, at heights which could not possibly be reached by the present river, and these deposits are clearly a continuation of the similar accumulations near Carstairs.

Some four or five miles below Carstairs the Clyde receives on its left bank the tribute of the Douglas Water, a considerable stream, draining a large area. It takes its rise on the slopes of Cairn Table, at a height above the sea of 1,500 ft., and reaches the Clyde after a course of fifteen or sixteen miles. In the lower reaches of its valley we find numerous heaps and mounds of gravel and sand, and sheets of the same

deposits are cut through by the Clyde opposite the mouth of the Douglas Water. These accumulations, however, are by no means so extensive as those in the neighbourhood of Carstairs.

Another considerable assemblage of mounds, hillocks, banks, and undulating flats of sand and gravel occupies a similar position in the Valley of the Kale Water, between the base of the Cheviot Hills and the river Teviot, near Eckford. This is a rather striking example of the phenomena under review. The Teviot here runs north-east, skirting the outlying spurs of the Cheviots, which are seen rising up boldly in the south. After receiving Jed and Oxnam waters, the river suddenly wheels away from the hilly ground and makes directly north for the valley of the Tweed, being joined about a mile below Eckford by the Kale Water. From this point the whole valley of the Kale, up to where the stream escapes from the Cheviots, at Morebattle, is more or less covered with gravel and sand, which rises into banks and mounds, and extends in broad undulating flats. Similar deposits are seen opposite the junction of the Kale with the Teviot on the west bank of the latter river. None of these accumulations could possibly have been formed by the present streams; they are not only too extensive, but they occur also at too great an elevation.

We find similar appearances characteristic of the Lammermuir districts. The Whiteadder Water, for example, after leaving the Lammermuir Hills, enters upon a low-lying undulating country, which is thickly strewn with sand and gravel over an area many square miles in extent; and the great bulk of these deposits is strictly confined to the drainage-area of the water. Along the northern flanks of the same hills similar phenomena recur, the low grounds being plentifully coated with gravel and sand opposite the mouths of the larger upland valleys.

Along the northern slopes of the Forth Basin excellent examples are not wanting. Considerable accumulations of gravel and sand extend over the low grounds of Kinross-shire, opposite the valleys that open from the Ochils. Again, if we follow the course of the Leven we shall find that, shortly after leaving the Loch, it flows through a great series of

mounds, hillocks, and banks of gravel and sand, which are especially well seen at Leslie and Markinch.

Reference may also be made to the great sand and gravel heaps that occupy the low grounds at the base of the Kilsyth Hills, within the drainage-area of the Carron Water.

Mounds, irregular banks, and extensive sheets of the like materials attain a very considerable development along the great trough that lies between the Perthshire Highlands and the Ochil and Sidlaw Hills. It will be found throughout this wide tract that the sand and gravel appear most abundantly opposite the mouths of the larger mountain-valleys.

In Forfarshire, and indeed along the whole north-east of Scotland, we invariably find that the greatest gatherings of gravel and sand are collected in similar positions, and that they frequently ascend the larger valleys for long distances. Vast deposits, for example, crowd the valleys of the Don, the Dee, and the Ythan, and the same appearances are repeated, as Mr. Jamieson has shown, in the rivers that drain north-east into the Moray Frith, as for example the Deveron, the Spey, and the Findhorn. In the neighbourhood of Inverness like masses of water-worn materials form conspicuous objects in the Vale of the Ness, and at the head of the Beauly Frith the lower reaches of the Farrar exhibit similar accumulations.

In all the cases now cited, and many more might be given, the extent of the gravel and sand deposits, which frequently assume the form of cones, peaks, and ridges, is as a rule proportionate to the drainage-area of the valleys in which they occur. The same fact becomes more conspicuous when we limit our attention to any well-defined hilly region of the central Lowlands. Take, for example, that broad, undulating hilly district, which, beginning at the Frith of Clyde, extends south-east along the borders of Renfrewshire, Ayrshire, and Lanarkshire, until it gradually falls away into the valley of the Clyde, near Strathavon. (See Plate III. p. 121.) This wide district forms the watershed between the Irvine and numerous small tributaries of the Clyde.

Along both banks of this wide, hilly, and moorland district it holds generally true that all the larger accumulations of gravel and sand are disposed at or near where the streams leave the hills and enter upon the low grounds—the extent

of these deposits being in proportion to that of the drainage-area and the height of the watershed. Valleys draining a limited district of low elevation have no marked accumulations of gravel and sand at their mouths; on the other hand, valleys draining from lofty sheds invariably contain in their lower reaches extensive deposits of gravel and sand, which are frequently heaped up into mounds, and the larger the valley the bulkier the accumulations of water-worn materials. These phenomena are well illustrated by the valleys of the Dusk, the Lugton, the Crawick, and the Crawfurdland Waters, and by the Avon and its tributaries—the Glengavel, the Calder, the Kype, and the Lochar Waters.

Enough, perhaps, has now been said to give the reader some notion of the mode in which the kames are distributed throughout the country. It is only necessary to add that the materials of which they are composed have in all cases travelled down the valleys.

If there have been many suggestions as to the mode of formation of till, the question of the origin of kames has no less taxed the ingenuity of geologists. At one time they were thought to be marine, and to have been heaped up by the action of tidal currents. But the absence of any trace of sea-shells or other organic remains was always considered somewhat mysterious, and had to be accounted for on the supposition that our kames were old submarine banks. Some writers, again, have suggested their fluviatile origin, while others have set them down as terminal moraines.

It is needless to enter into argument in order to show that the marine hypothesis is untenable. The form of the kames, their unfossiliferous character, and their geographical distribution, alike forbid the notion of their marine origin—a notion which, it may be added, has been definitely abandoned by students of glacial geology. We need now have no doubt that true kames are of morainic and fluvio-glacial origin. They are comparable, in short, to the morainic hummocks, ridges, and undulating terraces of gravel and sand that circle round the lower ends of the great Italian lakes, where one can be convinced they indicate the sites occupied by the terminal fronts of gigantic glaciers. The gravelly and sandy moraines at the foot of Lake Garda are precisely similar to

our Scottish kames. We can see now why it is that the largest assemblages of kames occur opposite the mouths of the greater valleys of the Southern Uplands and the Highlands, while similar accumulations are less well developed at the lower ends of valleys that drain smaller areas of high ground.

But before I attempt any further explanation of the 'gravel and sand series,' which is most typically represented by the kames of the Lowlands, it is necessary to glance for a little at certain phenomena which are best seen in the hilly districts of the country.

CHAPTER XVI.

DEPOSITS OVERLYING THE TILL OF SCOTLAND—*continued.*

Erratics and angular rock-débris of mountain regions and the Lowlands—Direction of transport of erratics - Distributed by ice-sheet and glaciers—Occurrence of erratics at higher levels than their parent rock-masses.

IN the Southern Uplands the upper boulder-clay or till is frequently covered by a coarse earthy-like agglomeration of angular rock-fragments and large blocks and boulders which show traces of glacial striæ, although as a rule these are faint. This débris, which is of very variable thickness, ranging from a few feet up to many yards, ascends to great heights upon the sides of the mountains, and may be traced far down the valleys even into the low grounds beyond. Thus, for example, the mountains that hem in Loch Doon (Ayrshire) are sprinkled with loose angular and subangular stones, some of them striated, and with immense numbers of large boulders of grey granite which do not belong to the hills upon which they rest, but have travelled outwards from the central mountain region. The angular débris, as we trace it down the valley, appears to become thinner and thinner, until, when we reach the low grounds about Dalmellington, it cannot be distinguished. But the grey granite boulders are more easily detected, and appear here and there on the hill-sides for several miles farther down the valley. They are not, however, confined to the immediate slopes of the valleys of that district, but are scattered promiscuously over all the hill-tops up to a height of 1,700 ft. In the valley of the Stinchar, which drains the same mountain-tract, similar appearances may be noted; angular rubbish, occasionally forming irregular hummocks and low mounds, and large boulders are scattered abundantly over the hill-slopes down as far, at least, as the village of Colmonell, and they

even appear near the very top of Beneraird (1,400 ft. above the sea). The same facts have been observed in the valleys that drain towards the Solway Firth. The wild mountain-tracts of Galloway that overlook the Water of Luce, the Cree, the Ken, the Urr, &c., are abundantly coated with earthy débris and angular rock-rubbish. Everywhere great boulders are distributed over the valley-slopes and hill-tops, and even over the low grounds beyond. Thus the low-lying Rinns of Galloway, according to Mr. D. R. Irvine,[1] show numerous loose boulders of grey granite which have come from the hills of Cairnsmore to the north-east. In all these districts, in short, there is abundant evidence to show that both the angular débris and the boulders or erratics have radiated outwards from the central knot of mountains down all the principal valleys to the low grounds. We meet with the like phenomena in the valleys of the Clyde and the Tweed. Loose earthy and clayey rubbish, containing some scratched stones, and large erratics sprinkle the sides of the hills up to considerable heights, and this for many miles down the course of those valleys. In the Tweed valley, for example, such débris appears in decided masses at Drummelzier, and it occurs loosely scattered over the valley-slopes even as far down as Traquair. The deep glens of the Highlands present us with similar phenomena. The mountain-slopes are everywhere sprinkled with loose earthy rubbish, in which a few faintly glaciated stones sometimes occur, and large erratics occur up to all levels, even as high as 3,000 ft. according to Mr. Jamieson.

The angular rubbish is unquestionably of morainic origin —it answers in every respect to the rude débris which gathers on the surface of an alpine glacier and is shot over the end of the ice, where it mingles with the detritus pushed out from underneath, to form a terminal moraine. It speaks to us, then, of a time when all the mountain-valleys were yet filled with ice—with massive local glaciers, the direct descendants of the great ice-sheet that produced the till or boulder-clay. While the upper boulder-clay was being deposited the ice-sheet continued to retire, until at last it no longer reached the sea, but deposited its moraines upon the land. It still

[1] See *Mem. Geol. Surv. Scot.*, Explanation of Sheet 3, par. 39.

covered a large part of the Lowlands, but such hills as the Lammermuirs, the Pentlands, and the Ochils now rose above the level of the *mer de glace*, while in the Highlands and the Southern Uplands the ice was restricted, for the most part, to the valleys. It was only under conditions such as these that the morainic débris, sprinkled over the hill-tops and occurring far down the valleys, could have been deposited.

Now let us glance for a little at the testimony of the erratic blocks, and see how this agrees with the evidence yielded by the ancient morainic débris.

Erratics are of all shapes and sizes—occasionally reaching

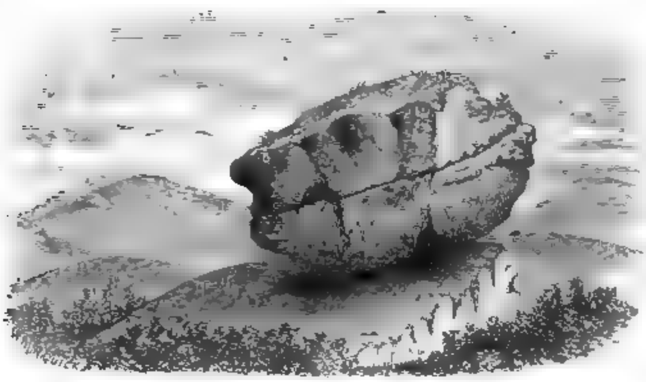


Fig. 49. Erratic resting on *roche moutonnée*. (A. H. Green.)

colossal proportions, and containing many hundred cubit feet. Some are well rounded, others only partially so, and very many are angular and subangular; not a few also show one or more scratched surfaces. In certain districts they are exceedingly abundant. I have already described how they occur in the valleys of the Southern Uplands and are plentifully scattered over the hill-tops up to considerable heights in that region, and how common they also are in the low grounds that sweep out from the base of these hills. Reference has likewise been made to their frequent occurrence in similar positions in the Highlands.

In the intermediate Lowlands they are not wanting, but large numbers have disappeared in the progress of agriculture,

so that they are not so plentiful as they used to be. But upon the slopes of those more or less isolated hilly tracts which rise up between the Highlands on the one hand and the Southern Uplands on the other, they are often abundantly met with. Along the northern flanks of the Sidlaws and the Ochils, for example, we find them thickly strewn. They consist in those districts of such rocks as mica-schist, gneiss, granite, &c., all of which have evidently been derived from the Highlands to the north and north-west. Boulders of similar rocks also make their appearance still farther south. They are met with here and there in the low-lying parts of Fife, and Mr. Maclaren has described the occurrence of a large mass of mica-slate at a height of 1,020 ft. on the Pentland Hills—the nearest rock from which it could have come lying fifty miles to the north, or eighty miles to the west. Boulders of Highland rocks have also been noted on the northern slopes of the Lammermuir Hills. They likewise occur in considerable numbers on the crests of the trappean heights that rise between the valleys of the Clyde and Irvine. In the south-west of Scotland, as already indicated, those undulating and hilly districts that roll out from the foot of the Galloway mountains are studded with innumerable boulders which have radiated outwards from the central heights. Even the islands that lie off the coasts are dotted over with loose boulders or erratics, which can frequently be shown to have travelled great distances. Thus, for example, I found in Lewis large erratics of red sandstone, and certain porphyries which, from their position, could only have been derived from the mainland.

Erratics rest on bare rock, till, and angular débris alike, and they are also found, as we have seen, on the slopes of åsar and kames. The position they occupy in the mountain-valleys is often precaricus—perched at a great height on some narrow ledge or jutting point of rock, where it would seem as if a slight push might send them bounding to the bottom.

As a general rule they prove to have been carried from higher to lower levels; the rocks of which they once formed a part stand at a greater elevation than those upon which they now repose. But to this rule there are exceptions; for

loose boulders are occasionally found at a considerably greate height than the rock from which they have been broken.[1]

What, then, do we learn from the erratics? How do w account for the scattering of these far-travelled blocks ove we may say, the whole face of the country? Some of them it is evident, must have crossed wide valleys and considerabl hills before they came to a final rest. The Highland boulder on the Pentlands and the Lammermuirs, for example, afte crossing Strathallan or Strathearn, traversed either th Campsie or the Ochil Hills, and passed athwart the broa vale of the Forth before they finished their journey. B what agent were they transported? The answer is—by th great ice-sheet. In like manner the numerous grey granit boulders that strew the slopes of the Galloway mountain and are found distributed far and wide over the low ground at their base; the boulders that cluster so numerously alon the northern face of the Sidlaws and the Ochils; the perche blocks that occur up to great heights in the glens and valley of the Highlands; and those that dot the surface of Orkne and Shetland and the islands of the Hebrides, have bee dropped where we find them by glacier-ice.

It is a fact that most, if not all, the erratics have travelle in directions that coincide with the trend of the rock-stria Thus in Lewis we get boulders of pre-Cambrian sandstone o the beach at Barvas (on the west side of the island), and at th Butt, which have evidently travelled either from Stornoway or the mainland; now the low grounds of Lewis are glaciate from south-east to north-west. In Aberdeenshire and Forfa all the erratics have streamed outwards from the mountain It is the same in Perthshire, Argyle, Ross, and other Highlan districts. In the southern counties the same rule hold strictly true. The erratics lying loose upon the ground hav moved in the direction followed by the till of the sam regions—a direction which it need hardly be said coincide with that of the underlying rock-striations. Indeed, whe the till is carefully searched it not infrequently yields frag

[1] Some of the most remarkable examples of this kind are met with in Gallo way. My colleague, Mr. J. Horne, found large erratics of granite up to a heigh of 2,764 ft. on the Merrick - the highest level reached by the granite *in pla* being only 2,270 ft.

Fig. 50. Coolin Mountains, Skye. Erratics resting on glaciated rocks in foreground. (H. M. Skae.)

ments of the same rocks as those of which the erratics lying loose at the surface are composed. Thus, as mentioned in a previous page, fragments of Highland rocks are got in the till of the Ochils, the Campsies, and the Paisley Hills. I have seen also bits of mica-schist in the till at Reston in Berwickshire.

Let us for a moment recall the appearance presented by Scotland during the accumulation of the till, and then consider what would be likely to result upon a gradual change of climate. When the cold was at its climax one great sheet of snow and ice enveloped the whole country, above which perhaps only the tips of some of the higher mountains appeared. As this ice-sheet melted away, more and more of the mountain districts would peer above the waste, and frost would then rupture the rocks—and rubbish, and débris, and great blocks falling upon the ice, would be carried outwards in the direction of its flow. In this way long trains of erratics would be travelling north, south, east, and west, from the Highlands, and in similar directions from the Southern Uplands. As the ice continued to melt, hills like the Pentlands would begin to rise above the level of the ice, and form islands in a great *mer de glace*; and just as the retreating tide will strew the beach with the waifs of ocean, so the ice-current, as it pressed upon and slowly crept away from these desolate islands, would leave upon their frozen shores the wreckage of the distant mountains. The surface of the ice still sinking, erratics would be left stranded on mountain-slopes and hill-sides at ever-decreasing levels, until the *mer de glace* finally disappeared from the Lowlands.

It would thus appear that the erratics belong to different stages of the glacial epoch. Those that lie upon the islands, and at great heights on such hills as the Pentlands, were, in all probability, stranded at a time when the upper boulder-clay was still accumulating, while those occurring at lower levels, and nearer to the mountains, must date to a later stage.

Among the many puzzling phenomena which glacialists have endeavoured to explain, not the least perplexing is the occurrence of loose erratics and perched blocks at considerably higher levels than the rock-masses of which they once formed

a part. Such erratics have been noted, not only in this country, but in glaciated regions elsewhere; perhaps the most remarkable examples being those which Scandinavian and American geologists have made known to us. Mr. Darwin, many years ago, attempted to explain such anomalies in the glacial phenomena of our own country by supposing that the erratics had been floated about on massive icebergs during a period of depression. He conceived that, as the land sank down, the bergs stranded or dropped their stony burdens at higher and higher levels of the drowning country. This ingenious explanation compels us, of course, to make one of two assumptions—namely, either that the movement of depression was rapidly effected, or that the icebergs were endowed with extraordinary longevity. Or, again, we might combine the two assumptions, and hold both that the downward movement was rapid, and that the icebergs took long years to melt away. I fear, however, that the theory is more ingenious than satisfactory. There are many considerations that militate against it, amongst which I shall only mention this, that we have no evidence of such a degree of submergence having obtained as would be necessary to account for the elevated position of many of the erratics in question. There are, no doubt, other objections which might be urged to Mr. Darwin's explanation; but it is hardly necessary, at least for my present purpose, to specify the reasons that have led me to the belief that another explanation of the difficulty must be sought for.

The opinion held by Scandinavian geologists, and by many glacialists in this country, with whom I have conversed upon the subject, is that the erratics under review have been deposited in their present positions by land-ice. No one, however, has yet succeeded in showing how land-ice could have carried these large blocks from lower to higher levels. It is obviously impossible that the boulders could have travelled upon the surface of the ice in the usual way, nor is it credible that they could have been pushed on underneath along with the *moraine profonde* or till—for frequently they show no marks of abrasion or striation, but are in all respects similar to the large angular blocks that fringe the sides of Alpine glaciers.

Many years ago I was led to believe that an explanation of the difficulty might be found in certain phenomena observed in Alpine glaciers. Among the late Principal Forbes' numerous letters on Glaciers, addressed to Professor Jameson, there is one bearing date December 12, 1846, in which some remarkable observations are recorded. The phenomena in question relate to 'the supposed tendency of glaciers to reject impurities, and the undoubted fact that stones are always found near or upon the surface of the ice.' 'It is strange,' says Forbes, 'that it should not have occurred to everyone who sought to explain the appearance of stones on the surface by the *ablaticn* of the ice, that in order to arrive there at all, the blocks must previously have been embedded in the virgin ice, where popular belief, and, generally speaking, more accurate observations also, give them no place.' Forbes then proceeds to give several examples of the phenomena, which I cannot do better than quote in his own words. Referring to the extruded stones on the Glacier du Nant Blanc, near Chamouni, he remarks that 'the right bank of this glacier is at first bounded by rocky summits, but in the lower part of its course by a mound-like moraine of the usual form. The surface-blocks can only be derived from the precipices near the origin. Yet they do not even appear on the surface opposite the rocks, but only opposite to the moraine; and they increase in number and quantity towards the lower end of the glacier, where they almost blacken the surface of the right side, the left side remaining almost clean. It is difficult to believe that this accumulation is not due to the gradual denudation of the blocks by the melting of the ice in which they have been in some way or other embedded; but it is scarcely less difficult to admit that having fallen from the rocks above the *névé*, they should have remained unperceived in the ice during all the intermediate space.

'To take another example. The Glacier of the Rhone is distinguished by the extraordinary purity of its surface, and the consequent absence of lateral moraines. But this general freedom from stones on the surface is subject to one exception, which is remarkable. *Stones begin to appear at the surface on the terminal slope at a considerable height.* How

came they there? Not a stone the size of the fist can be seen on the surface farther up; and in examining a number of the crevasses I could not see any engorged in the ice. The explanation seems to be, that these stones are actually introduced into the ice by friction at the bottom of the glacier, and forced upwards by the action of the *frontal resistance* which produces the *frontal dip* of the veined structure, and they are finally dispersed on the surface by the melting of the ice.' [1]

The facts recorded by Forbes have an interest for geologists, apart altogether from their bearing on the cause of glacier-motion. Whether, as Forbes supposed, stones are carried upwards through the solid mass of a glacier by the filamentary sliding of the particles of ice—the curves of ejection corresponding exactly with those of forced separation —is a question for physicists to consider. What we do know is that stones apparently do travel upwards through the ice, nor will *ablation* alone suffice to explain the fact. If, for example, a boulder which has fallen into a crevasse and become embedded at a depth of 80 or 100 ft., should reappear upon the surface of the glacier at a point farther down the valley, it is evident that its reappearance at a relatively higher level in the glacier cannot be due to the melting of the ice alone. At one place it lies at 80 or 100 ft. below the surface, but after the glacier has flowed for some distance, it reappears at the surface; that is to say, it seems to have risen 80 or 100 ft. through the ice. If 80 or 100 ft. of ice have been removed by melting and evaporation, then this loss has been again made good, but not by the accumulation of snow upon the surface of the glacier—the ice has been kept at its general level by the new supplies which are continually pouring into the valley at its origin. In other words the ice in front rises just as fast as the ice advances from behind; it is thus that the general level of the glacier is maintained. Now the line of ejection along which the boulder has travelled cannot possibly dip at the same angle as the slope of the valley; for if that were the case the boulder would always remain embedded in the ice, at the same distance from the underlying rock, until it was ejected

[1] *Edin. Phil. Journ.* January 1847.

at the terminal front of the glacier. But although the line of ejection must always dip at a less angle than the valley, yet it will in most cases still have a more or less perceptible dip in the same direction as the valley. A great deal will depend upon the boldness of the obstructions that impede the flow of the glacier. If these are numerous and formidable, then the lines of ejection will approximate more and more to the horizontal, and even at last curve upward so as to dip *up* instead of *down* the valley; and thus boulders introduced into the ice at a given point will, as they are borne down the valley, not only rise as it were through the glacier, but eventually be extruded at a level which may be many feet, or even many yards, higher than the point in the valley from which they originally started.

It seems to me that such must be the case, no matter what theory of glacier motion we hold.

Now, if stones introduced into the body of a glacier whether from above or below, tend to rise upwards in the ice as the glacier flows on its way, we may ask whether this fact does not throw some light on the curious problem which forms the subject of our present inquiry? Let us picture to ourselves a mountainous country, such as Scotland or Scandinavia, covered with a wide ice-sheet, or series of confluent glaciers, and endeavour in imagination to follow the course of some hypothetical boulder which has become embedded in the ice. We shall conceive that this boulder has been introduced into the ice at or near the bottom of some valley in the interior of the country. As the ice creeps outwards the stone gradually rises, the path which it follows sloping at a less angle than the bed under which the ice flows. Did no obstruction intervene, it is evident that the boulder, while it rose through the body of the ice, would be at the same time travelling gradually to lower levels than the point from which it originally set out. And it is quite conceivable that under such circumstances a stone might rise as it were through a thickness of several thousand feet of glacier ice and yet be eventually extruded at a lower level than the rock of which it once formed a part. But then we know that countless obstacles intervened to impede the flow of the massive ice-sheets of the Glacial Period; and with every such

obstruction the glacier-masses must have been forced to bulge upwards by the intense *vis a tergo*; and such upward movement of the ice, being again and again repeated, imprisoned boulders and débris would be compelled just as often to rise to higher and higher levels. Let us suppose that our hypothetical boulder is travelling in a nearly level course towards some ice-smothered hill. As the ice approaches this obstacle, it begins to bulge upwards, and our boulder is, as it were, forced up an inclined plane. Eventually, however, the ice sweeps round and overflows the obstacle, and thereafter continues on its course. There being now less longitudinal pressure, the included boulder will not rise so rapidly, but will travel either in a horizontal line, or down a gently-inclined plane. Let us suppose, further, that such obstructions to the flow of the ice supervene again and again, until at last the boulder is carried into some embayed recess of the ice-drowned country, such as one may see represented in miniature by sheltered hollows in the bed of a river. Now, in such a recess our boulder may linger for a considerable time, but as the ice is always melting and evaporating at the surface, and the loss thus caused is being continually made good by the advance of ice from behind, it is evident that unless the stratum of ice containing our boulder manages to creep out of the embayed recess as an 'undertow,' it will be forced to rise higher and higher until it becomes coalescent with that portion of the current which overflows all obstacles at a higher level. By this time our boulder, having travelled, let us say, fifty or a hundred miles, may have been carried to a level many hundred feet or yards above that from which it originally started. We have now only further to conceive that, after a greater or lesser number of such vicissitudes, the boulder is at last extruded at the surface, and stranded on the side of some rocky hill that peers like an island above the surface of the far-stretching *mer de glace*.

Now, cases like this must have occurred again and again during the growth, continuance, and decay of the massive ice-sheets that once enveloped Scotland. We know from actual observation that just such obstacles as I have alluded to did really obstruct the flow of the Scottish ice. The con-

fluent glaciers were frequently deflected, now to the righ now to the left, sometimes by opposing high grounds, at othe times by masses of ice flowing in a different directior This we can read in the trend of *roches moutonnées* and stria in the dispersal of the stones in the till, and the distributio of loose erratics and perched blocks. Nay, we have eve clear evidence to show that sometimes the under strata o the ice flowed in one direction, while the ice sweepin along at the surface followed a different route. Henc we can have no difficulty in admitting that such heapin up and bulging of the ice as is required to account fo the transport of boulders from lower to higher levels mus frequently have taken place in Scotland during the Glacia Period.

The generally non-glaciated aspect of the boulders i question is also perfectly accounted for on the theory I hav ventured to advance. Once embedded in the ice, stones an boulders might travel for hundreds of miles without suffe ing abrasion. The well-known incident of the knapsack which was lost in a crevasse of the Glacier du Talefr on July 29, 1836, and disgorged by the coalescent Glacie du Léchaud on July 24, 1846, after having travelled, em bedded in the ice, over a distance of 4,300 ft., shows ho little change a lump of hard rock would sustain in tra velling through a mass of glacier-ice. Occasionally, how ever, such an included block might be rubbed against th rocks of a hill-side, and so receive a dressing on one c more faces.

The foregoing remarks have reference only to erratic which have been subjected to little or no glacial abrasion- which, in short, have not been dragged forward underneat the ice. Such erratics come under the category of 'inne moraine,' as described in Chapter IV. But the groun moraine itself has often travelled up-hill—the till of son hilly regions, such as the Sidlaws, being charged with ston which have come from lower levels. As we have alread seen, the ice in its course across Central Scotland overflow such hills and necessarily dragged its ground-moraine with i

[1] *Edin. Phil. Journ.* January 1847.

CHAPTER XVII.

ORIGIN OF DEPOSITS OVERLYING THE TILL OF SCOTLAND.

Origin of the later glacial deposits—Stranding of erratics and rock-débris during melting of ice-sheet—Fluvio-glacial action—Formation of åsar, kames, and gravel terraces—Deposition of sediment in ice-dammed lakes—Morainic accumulations in mountain-valleys.

WE have now discussed the character of the more or less incoherent accumulations of gravel, sand, silt, and angular débris, which, in many parts of Scotland, are found resting upon the surface of the upper boulder-clay. Whatever doubt we may have as to the origin of those accumulations, we can at least be certain that they are of later date than the till which so frequently underlies them. It will be remembered that I have described them under these heads, namely: (1) Åsar, or ridges of gravel, &c., which coincide in direction with the trend of the glaciation—they follow, in short, the path of the ice-sheet; (2) Terraces and irregular ridges and banks of gravel, sand, &c., which fringe the slopes of hills that overlook the lowland tracts, and frequently appear in upland valleys, running along the sides of the hills, spreading out over watersheds, and now and again passing across cols from one drainage-area into another; (3) Kames of gravel, sand, &c., which are typically developed in the Lowlands opposite the mouths of mountain-valleys, and which, when followed up such valleys, pass eventually into ordinary morainic accumulations; (4) Morainic débris and erratics sprinkled over the tops and slopes of the Lowland heights, abundantly developed in mountain-regions, but occurring at all levels down to the sea-coast.

It may be premised that we cannot always draw a hard and fast line between those various accumulations, neither can we say that one set is older than the other, although it

is obvious that they cannot all be contemporaneous. It is clear, however, that they belong to the time when the great *mer de glace*, underneath which the upper boulder-clay accumulated, was wasting away. In a word, they are of fluvio-glacial and glacial origin.

After the surface of the ice-sheet had been considerably lowered by ablation, a time would come when the higher hills of the Lowlands peered above the level of the *mer de glace* like islands, while the mountain-ridges of the Highlands and the bold hills of the Southern Uplands slowly emerged so as to separate the formerly confluent ice of those regions into a series of great valley-glaciers, which, however, still coalesced upon the broad Lowlands. As the mountain-tops became uncovered enormous quantities of rock-débris together with great blocks would be detached by frost and shoot down to the surface of the ice. Sometimes the boulders and stones would fall into crevasses or between the ice and the mountain-slopes, where they might get rubbed and striated on one or more sides. The ice as it flowed on its way would thus become charged with rock-débris—much of it lying on the surface as superficial moraine, and some proportion doubtless included in the mass of the *mer de glace* as intraglacial. In this way the ice that streamed out from the mountains over the Lowlands, during the period of decadence must have been in many places more or less charged with rock-fragments. The tops of the Lowland hills peering above the surface would doubtless catch some of the wandering blocks as they drifted past, but many more would be carried out to the terminal front of the ice.

As the ice continued to melt, erratics and angular débris would be stranded at ever-decreasing heights upon the mountain-slopes and hill-sides. So long as the ice attained any considerable thickness and continued to flow, the formation of its ground-moraine would not cease. Eventually, however, a time would arrive when the ice on the Lowlands would become more or less inert and dead, and boulder-clay would then no longer accumulate. We may readily believe, however, that throughout all the stages of decay running water would play a prominent part. Countless streams and rivers would traverse the surface of the ice-sheet, just as in

summer is the case with the maritime areas of the inland ice of Greenland. Thus much of the angular rock-rubbish lying upon and included in our old *mer de glace* would be hurried forward and be subjected to powerful attrition by torrential waters. In some places, as Dr. Holst suggests, the beds of these supraglacial rivers might become crowded with gravel, sand, and angular and subangular débris, and it is conceivable that such river-courses, during the later stages of dissolution, might persist until their beds had sunk to the bottom of the attenuated ice-sheet. When the ice finally melted away such river-courses would appear as åsar. The Scottish åsar, however, are so frequently interrupted, and often stop so abruptly, that we can hardly suppose that the narrow troughs in which they accumulated continued to be traversed by supraglacial rivers down to the final disappearance of the *mer de glace* from the Lowlands. But, owing to the unequal ablation of the ice-sheet, the superficial drainage system might well be again and again modified—old stream-courses being from time to time abandoned and new ones formed. In this way we may have an explanation of those short ridges and solitary mounds of gravel and sand that now and again appear dotting the surface of broad flats of till in the Lowland districts. Most of our åsar, however, would appear to have been formed underneath the ice. One can well conceive how the narrower gravel-ridges may have been accumulated in more or less constricted tunnels, through which the subglacial waters would rush with violence, while accumulations of finer-grained materials would be deposited in places where the width of the watercourses was considerable. It is possible too that where lateral channels opened into the main subglacial water-ways, little cross-currents would give rise to confused stratification and false-bedding. Similar results, indeed, might take place without the intervention of tributary streams: for the volume of water circulating under the ice would be liable to much variation. It would increase and diminish with the change of the seasons; and even during one and the same season the quantity of water descending by moulins and crevasses, or seeking its way down between the ice-sheet and the mountain-slopes and hill-sides that rose above its surface, would vary day by day with the

external temperature. And such constant variations in the volumes of the streams would of itself give rise to many modifications of bedding in the subglacial deposits of sand and fine gravel.

But whether the Scottish åsar were formed in supraglacial or in infraglacial water-courses, or, as seems to me most probable, were accumulated in both, it is quite certain that they belong to the period of dissolution of the last general *mer de glace*, and unquestionably mark the sites of glacial rivers and torrents. When the more continuous and well-preserved åsar were being formed, the movement of the *mer de glace* in the lowlands had doubtless been arrested, so that the course of the subglacial torrents experienced little or no disturbance. The materials of the åsar, as we have seen, were derived partly from the morainic débris resting upon the surface of the *mer de glace*, but partly also from that included in the mass of the ice itself. In the case of such åsar as were formed underneath the ice, probably no inconsiderable proportion of the deposits was obtained from the underlying boulder-clay or ground-moraine, which often shows a much denuded surface below the gravel. Closely allied to our åsar are those terraces and ridges of gravel and sand which I have described as fringing the slopes of upland valleys and hill-ranges. Indeed these seem to have had practically the same origin—the terraces and flats having been formed in the beds of temporary glacial lakes, while the ridges connected with them indicate the course of contemporaneous marginal and infraglacial and supraglacial streams and torrents.

Eventually a time would come when the ice had melted away from all the low grounds, leaving behind it great gravel åsar, stretching along the broader valleys and moorlands—terraces and irregular heaps and ridges of similar materials fringing hill-slopes—and erratics of all shapes and sizes sprinkled over the surface of the country from the tops of the Lowland hills down to the bottoms of the valleys. The materials entering into the formation of åsar, terraces, &c., consist, as we have seen, chiefly of more or less water-worn detritus. In some parts of the Lowlands, however, we occasionally encounter low mounds and irregular sheets of

earthy angular débris, associated with which are larger erratics and now and again some gravel and sand. These are probably of morainic origin—the loose materials formerly resting upon or included in the *mer de glace*—dropped where we now see them on the final dissolution of the Lowland ice.

Long after the ice had vanished from the Lowlands, however, great glaciers continued to cumber the mountain-valleys of the Highlands and the Southern Uplands. For a time those glaciers were here and there confluent on the low grounds at the foot of the mountains, but eventually each retired to its own valley. The ice being crowded with débris and abundantly washed by running water, we can readily understand how considerable terminal moraines would begin to accumulate whenever the retreat of the glaciers was temporarily arrested. In the case of valley-glaciers that drained inconsiderable areas of no great elevation, the ice would appear to have melted away continuously, so as to leave no prominent moraines or sheets of morainic materials. But in the larger glens, receiving the drainage of wide and lofty regions, the glaciers maintained their position for a longer time. Opposite the mouths of such great mountain-valleys, therefore, moraines are usually strongly developed. These are the regions, in short, in which we find the most conspicuous assemblages of kames—the gravelly 'moraines of retreat.' We can now understand why it is that kames bulk most largely opposite the mouths of our greater valleys. Their presence there in such abundance shows that the larger glaciers maintained their terminal fronts in such positions for a considerable period. Now and again, indeed, after a succession of seasons of heavy snowfall had greatly replenished their frozen reservoirs, the glaciers even re-advanced, pushing moraines and torrential gravels before them, while at other times, neither advancing nor retreating, they made longer or shorter pauses, during which large moraines gathered in front which the rivers were unable to sweep away. Those rivers, we cannot doubt, were much larger than their present representatives. The very fact that the kames consist principally of water-worn materials shows us how potent a power running water exerted at the time of their formation. Torrents flowed upon the surface

of the glaciers, careered along their margins, and tunnelled them underneath, so that immense quantities of morainic débris were worked over, and gravel, sand, and silt abundantly produced. No inconsiderable proportion of the rock-débris, however, would escape attrition, and, travelling onward with the ice-flow, would topple over its front, where it would be associated in the terminal moraines with heaps of gravel and sand. Mr. Jamieson remarks of certain kames in the north of Scotland that they 'often lie across valleys in long sinuous lines, forming curves or segments of a circle, the concavity of which is presented to the head of the valley, and their convexity towards the sea or downward end, as in terminal moraines' 'The material they consist of and its mode of arrangement point to streams of water flowing over the surface of the glaciers, and washing the gravelly débris into heaps along their margins. A mass of gravel reposing against the side or end of a glacier would lose its support when the ice melted away, and, falling down in a slope, would assume the form of a steep-sided mound. Glaciers are subject to oscillations, sometimes advancing, sometimes receding, according to the varying nature of the seasons. Suppose the end of a glacier to push forward into a sheet of gravel lying in front, the result would be to force it up into a mound all along the edge of the ice.'[1] Mr. Jamieson further reminds us of another resemblance which certain kames bear to moraines, namely, that one side of the ridges is often steeper than the other—the same being the case, according to M. Collomb, with many of the old moraines in the Vosges Mountains.

We almost invariably encounter wide flats of gravel and sand closely associated with all groups of typical kames. This is very well seen in Strathmore, the bottom of which is paved with broad sheets of gravel, sand, and silt, that sweep outwards from the kames that are crowded together opposite the mouths of the great Highland valleys. Such flats were undoubtedly the work of flooded streams and rivers descending from the glaciers that occupied the glens —the waters being swelled in summer-time from the melting

[1] *Quart. Journ. Geol. Soc.* 1874, p. 329. I would call the special attention of the geological reader to this paper, which contains the first clear statement of the morainic origin of kames. Dr. Chambers, however, appears to have been the earliest to suspect their morainic character.

of the snow that mantled the adjacent Sidlaw Hills and the intervening low grounds themselves. From the great extent of those flood-deposits one can see that wide areas of Strathmore must have been subject to periodical inundations.

Along the base of the Southern Uplands similar phenomena may frequently be observed. Thus at the foot of the Lammermuir Hills, especially in the neighbourhood of West Gordon and Greenlaw, occur numerous kames, heaps, hummocks, knolls, and undulating flats of angular débris, gravel, and sand. Erratics now and again occur embedded in the deposits, while many of the mounds are crowned with similar angular boulders of various rocks, all of which have been caried from higher levels than they now occupy; most of them indeed, have come from the west, while others have been derived from the slopes of the Lammermuir Hills which lie immediately to the north. I may mention that the kames frequently repose upon a mass of very hard red till full of striated stones, and that the line of separation between the two deposits, when they occur together, is always very sharply defined; and this, I may add, is most frequently the case with the till and the overlying kames, although now and again both till and overlying gravel and sand have the appearance of having been pushed forward together.

A review of these and other appearances leads to the belief that when the kames along the foot of the Lammermuir Hills were being heaped up, the ice was fast disappearing from the major portion of these uplands, while heavy torrents, which must sometimes have flooded large areas of the low grounds, descended from the melting snow and ice. The tumultuous hummocks of gravel and angular débris are moraines, while the flats of finer materials show where the torrential waters expanded themselves over the low grounds. Some of the erratics in these deposits may have come on ice-rafts; for, during winter, the waters would become frozen over, and erratics and boulders lying loosely over the deserted path of the old ice-sheet might now and again get encased in ice, and be carried down the valley on the breaking up of the ice when the flood-season returned. 'Ground-ice' might also be a means of floating stones and boulders. The rafts would often drift into the quieter

reaches of the swollen waters, and there running aground on shelving sand-banks, would drop their stony burdens. Not a few travelled stones might at the same time be scattered promiscuously over the surface of the inundated districts, coming to rest sometimes upon sand or gravel, sometimes upon till or bare rock.

During the existence of these great valley-glaciers ice-dammed lakes must have existed in many parts of the mountain-regions. We might infer this from the configuration of the land itself. For many of the lateral valleys which opened into the main glens drain limited areas of no great elevation. A time would come then when the glaciers occuping such small tributaries would shrink back and even entirely disappear, the main trunk glacier the while continuing to maintain its position. In this way glacial lakes were formed—some of which appear to have endured so long that they were partially or even completely filled up with silt, sand, and gravel. When the main glacier had melted back—and the ice-dam was removed—the lacustrine deposits were excavated by the brooks; but fragments of them are still often found fringing the sides of the valleys and forming more or less distinct terraces, frequently at considerable heights above the present streams. Such horizontal ledges are not to be confounded with those old river-terraces which occur so frequently in many of the mountain-valleys of northern and southern Scotland. The latter slope with the inclination of the valleys in which they appear, and evidently mark former levels at which the rivers flowed when the body of water descending to the low ground was more considerable than now.

As the great glaciers continued to retire, the bottoms of the valleys would be strewn with morainic débris and coarse river-gravels, while erratics and rock-rubbish would be stranded on the valley slopes. So long as the ice occupied the lower reaches of those valleys the gradient of which is more or less gentle and uniform, it would flow steadily forward and show few crevasses. But where the gradients were steeper and irregular the ice would become more and more crevassed. Under these conditions superficial waters would be soon engulphed, and the overlying morainic débris

would escape attrition. The moraines of retreat, therefore, would tend to become successively coarser and coarser, until water-rolled stones and sand formed but a very insignificant proportion of their mass; and as the valleys narrowed, the tumultuous character of the moraines would ever be more and more pronounced. We thus explain the gradual change that overtakes the morainic materials as these are followed from the low grounds into the heart of the mountain-regions.

We see then that the formation of åsar, kames, erratics, and angular débris—of river-flats and lacustrine terraces—accompanied the dissolution of the great *mer de glace* underneath which, while it flourished, the upper boulder-clay of Scotland was accumulated. The great moraines which crowd the glens of the Highlands and many of the valleys in the Southern Uplands have been looked upon as relics of the latest period of extensive glaciation in Scotland. They are supposed to have been laid down by those large local glaciers into which the ice-sheet was resolved on its retreat from the Lowlands. We cannot, indeed, escape from the conviction that the last extensive *mer de glace* must eventually have broken up, as it were, into such a series of valley-glaciers. And we seem, therefore, forced to the conclusion that the moraines referred to mark the final stages in its retreat. A number of years ago, however, certain observations made in the Outer and Inner Hebrides, and in various parts of the Highlands and the Southern Uplands, led me to doubt whether, after all, the valley-moraines of those regions really pertained exclusively to the closing stage of the second epoch of glaciation. I am now convinced that they do not. It is without doubt true that the ice-sheet of the second glacial epoch must have passed away in the form of local glaciers, and left the mountain-valleys more or less crowded with morainic débris. But, as I shall endeavour to show in the sequel, the moraines now visible are not entirely the product of the second glacial epoch. They belong mainly to a third epoch of glaciation, which was separated from the preceding ice age by a prolonged period of interglacial conditions. But before I attempt to prove this it will be necessary to consider the origin of certain remarkable features of Scotland, of which as yet no special mention has been made.

CHAPTER XVIII.

ROCK-BASINS OF SCOTLAND.

Different kinds of lakes—Lakes occupying depressions in drift—Lakes dammed by moraines and older drift deposits—Lakes lying in rock-bound basins—Origin of rock-basins discussed—Ramsay's theory—Sea-lochs—Submarine rock-basins—Their glacial origin—Silted-up rock-basins.

WHEN we glance at a good map of Scotland, one of the first appearances to catch the eye is the wonderful profusion of lakes. Moreover, it will not fail to strike us that these lakes are confined, for the most part, to the deep valleys of the Highlands. From the lowland tracts they are singurarly absent. South of the Firths of Tay and Clyde comparatively few are seen, and these are nearly all restricted to the high grounds of Carrick, Galloway, and Peeblesshire. There would thus appear to be some connection between lakes and mountain-valleys. We cannot but see this when it is pointed out; yet it is barely more than thirty years ago that the attention of geologists was called to the fact. It was reserved for the late Sir A. C. Ramsay not only to indicate the very remarkable manner in which lakes are distributed in alpine and northern countries, but also to bring forward a satisfactory explanation of the phenomena.[1]

The Scottish lakes may be grouped under three heads, viz.:—

1. Lakes occupying hollows in the till or other superficial deposits.

2. Lakes dammed by glacial accumulations.

3. Lakes resting in basins of solid rock.

The lakes of the first group have no importance, and indeed are little more than shallow pools. They are developed chiefly in the Lowlands, and have at one time been much

[1] *Quart. Jour. Geol. Soc.* vol. xviii. (1862), p. 185.

more numerous than they are now. Many have been silted up with alluvial matter, others have been converted into peat-bogs, and not a few have been drained. They rest sometimes in the hollows between banks of till, and not infrequently in cup-shaped depressions of sand and gravel. The most considerable assemblage of these lakes of which I know is in the island of Lewis—the low-lying tracts of which are literally peppered with lakelets. Not a few of these, however, belong to the second group. But hundreds of them appear to rest in hollows of the till—their longer axis pointing north-west and south-east. They are, for the most part, very shallow, and have been much encroached upon by peat.

The lakes of the second group are also somewhat insignificant. Those which are dammed back by moraines are confined, as one would naturally expect, to mountain-valleys.

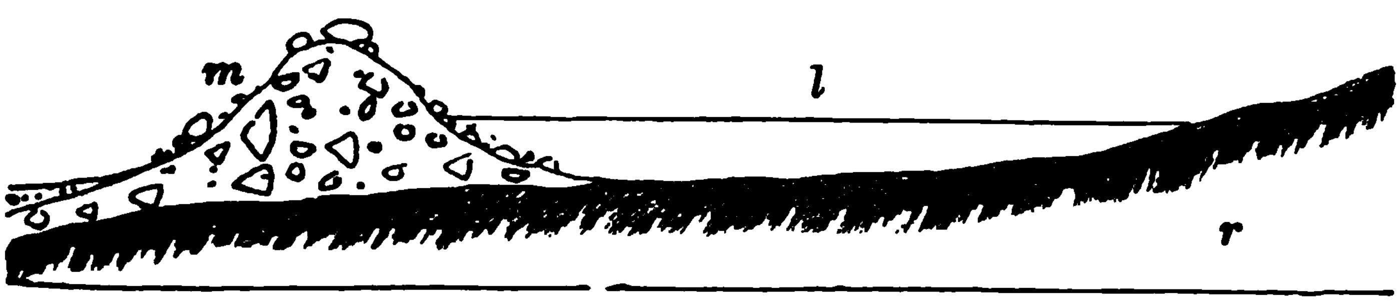


Fig. 51.—Morainic Lake.

An excellent example of the kind is that of Loch Skene, in the south of Scotland. In this instance a series of morainic mounds, left behind by one of the last local glaciers, extends from one side of a mountain-valley to the other, and has thus formed a barrier to the escape of the water. In not a few mountain-valleys where such lakes have at one time existed, we may see how the waters have been drained off by the gradual cutting down of the moraines. It is only, indeed, when the outlet of the water is over rock that a moraine-dammed lake can have a prolonged existence.

Besides the lakes which are confined behind barriers of morainic débris, we occasionally meet with small sheets of water which appear to rest partly in rock and partly in till or other superficial accumulations. Fine examples of this variety of lakelet occur in the low grounds of Lewis. Unlike the lakelets of the first group, which occur in the same region, the drift-dammed lakes do not range from south-east to

north-west, but exactly at right angles to that direction—namely, from south-west to north-east. They lie between parallel ridges of rock, and are dammed up at either end by accumulations of till. In Lewis[1] it is common to find both kinds of lake represented in one and the same sheet of water—one elongated portion of which will trend south-east or north-west, and another arm extend itself in a north-east or south-west direction, as the case may be.

In the Lowlands there are a few lakes, such as Loch Leven (Kinross-shire), the original shape of whose bed it is difficult to determine. Probably most of them, however, are merely due to the unequal distribution of the till and other superficial deposits over the underlying rocks. Others, again, may really belong to the third group, and occupy rock-basins the nature of which is now concealed by the accumulation of alluvial matter along their margins. I strongly suspect that Loch Leven is a case in point.

The third group embraces the largest and most important lakes in Scotland, and to it also belong a vast number of mountain-tarns which are neither large nor important. All these lakes and tarns rest in hollows of solid rock. In very many cases we may trace the rock all round their margins; and even when this is partially obscured by superficial deposits there are yet other circumstances which enable us to show that, were these deposits to be entirely removed, there would still be a lake completely surrounded by rock. These lake-hollows are what Ramsay has termed *rock-basins*; and his ingenious theory of their origin I must now attempt to describe.

When we reflect for a moment, we shall find that it is a very hard thing indeed to account for a rock-basin. The usual agents of erosion, those which we see at work in our own country, fail to afford any solution of the problem. We may, for example, dismiss the sea as quite inadequate. The action of the sea upon the land is that of a huge horizontal saw; the cliffs are eaten into, and gradually undermined; masses of rock, loosened by rains and frosts, tumble down, and are pounded up by the breakers into shingle and sand.

[1] The features referred to are beautifully delineated upon the Ordnance Survey Map of Lewis. See paper by author, *Quart. Journ. Geol. Soc.* 1873.

Thus in process of time a shelf or terrace of erosion is formed, and were the shore to be sufficiently elevated to-morrow, we should find that such a platform would extend all along our rocky coast-line—narrowing where the rocks were hard and durable, broadening out where the cliffs had yielded more easily to the ceaseless gnawing of the waves. But nowhere should we be able to detect anything approaching to the character of a rock-basin; for it is self-evident that the sea 'cannot make a hollow below its own average level.' Its tendency, indeed, is quite in the opposite direction—much of the material derived from the denudation of the land being carried out and deposited in quiet depths.

If the sea does not help us to discover how rock-basins are formed, will rivers do so? Most assuredly they will not. Rivers will flow down any slope, but they cannot run up an inclined plane. What they do is to cut channels which carry them down persistently from higher to lower levels. The only approach to something like a rock-basin which can be excavated by river-action may be observed at the foot of a waterfall, where a more or less deep hollow always appears. This hollow is of course scooped out by the filing action of the stones and pebbles which are kept in constant motion by the falling water. But it would be idle to suppose that such has been the origin of the rock-basins. Yet this action of the falling water, as I shall try to show presently, may aid us in appreciating more fully Ramsay's theory.

Since rock-basins owe their origin neither to rivers nor to the sea, may not they be simply due to disturbances of the strata? We know that the rocks of which our country consists have been elevated and depressed times without number since the date of their formation. We know further, that they have been dislocated and displaced by movements of the earth's crust, and confused by the intrusion among them of molten materials; and this has happened over and over again. Strata which we have every reason to believe were laid down in horizontal or approximately horizontal planes have been puckered and thrown into innumerable folds. May not the lakes, then, occupy troughs in the crust, or rest in cracks and chasms or depressions caused by dislocation and displacement of the rocks? To those who have made no

special study of physical geology this may appear a ready and simple explanation. In sober truth, however, it is no explanation at all; for when we come to examine the rock-basins themselves, we do not find them occupying 'hollows formed of strata bent upwards at the edges all round into the form of a great dish, the uppermost bed or beds of which are continuous and unbroken underneath the waters of the lake.' No such synclinal troughs occur anywhere in Scotland; indeed, as Ramsay has remarked, they are the rarest things in nature. As a general rule, we find that in regions which have formed land-surfaces for a protracted period synclinal troughs or geological hollows usually form hills, while conversely anticlinal ridges or geological hills generally give rise to valleys. And it not infrequently happens that the hollow in which a lake lies is, geologically speaking, a hill or anti-

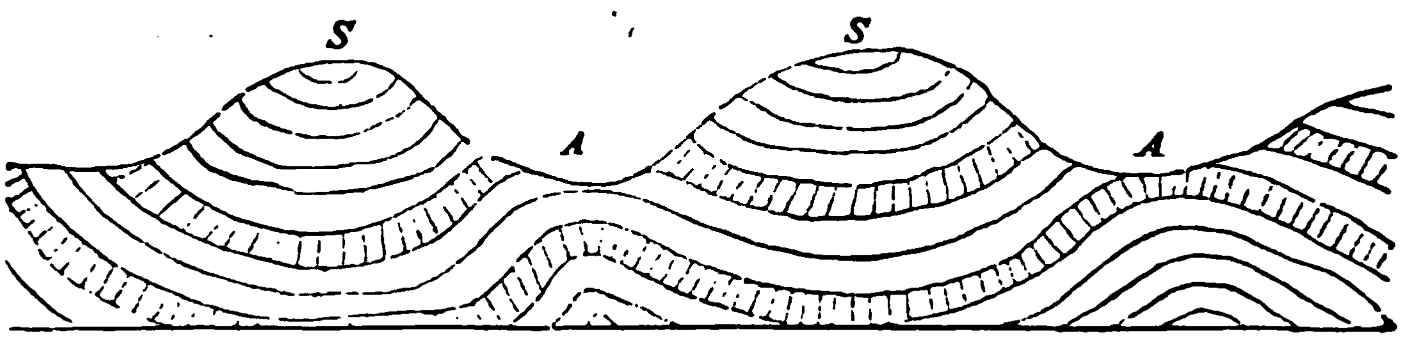


Fig. 52.—Diagrammatic view of synclines and anticlines. *AA*, anticlinal arches; *SS*, synclinal troughs.

cline. But still more frequently rock-basins occur in regions where the strata are 'bent and contorted in a hundred curves all along and under the length of the lake,' nor does the direction or slope of the basins bear any relation whatever to the prevailing inclination of the strata. We may conclude, then, that the bedding of the underlying rocks affords no clue to the solution of the problem.

Do the lakes lie in gaping fissures, or in chasms produced by dislocations of the solid rocks, or, as they are technically termed, *faults*? As a matter of fact, no single instance has yet been adduced, either at home or abroad, where a *fault* could be demonstrated to be the proximate cause of a lake-hollow. My duties in connection with the Geological Survey afforded me exceptional opportunities for the study of dislocations and displacements. Having mapped the major portion of the coal-fields in the west of Scotland—a highly

dislocated area—I found, as the result of a minute examination of all the carefully-prepared mining-plans and a close investigation of the ground, that none of the faults ever gave rise to any feature at the surface, save when a hard rock like basalt was brought into juxtaposition with a relatively soft rock like sandstone. In such a case the basalt-rock almost invariably gave rise to a prominence. Now many of these faults are 20, 40, 60, and some even 100 fathoms in extent, and they frequently cross and shift each other; yet no yawning cracks or irregular depressions at the surface give one any indication of their existence. In walking over a level turnip-field one may traverse a dozen in the space of a few hundred yards. My impression is that none of these

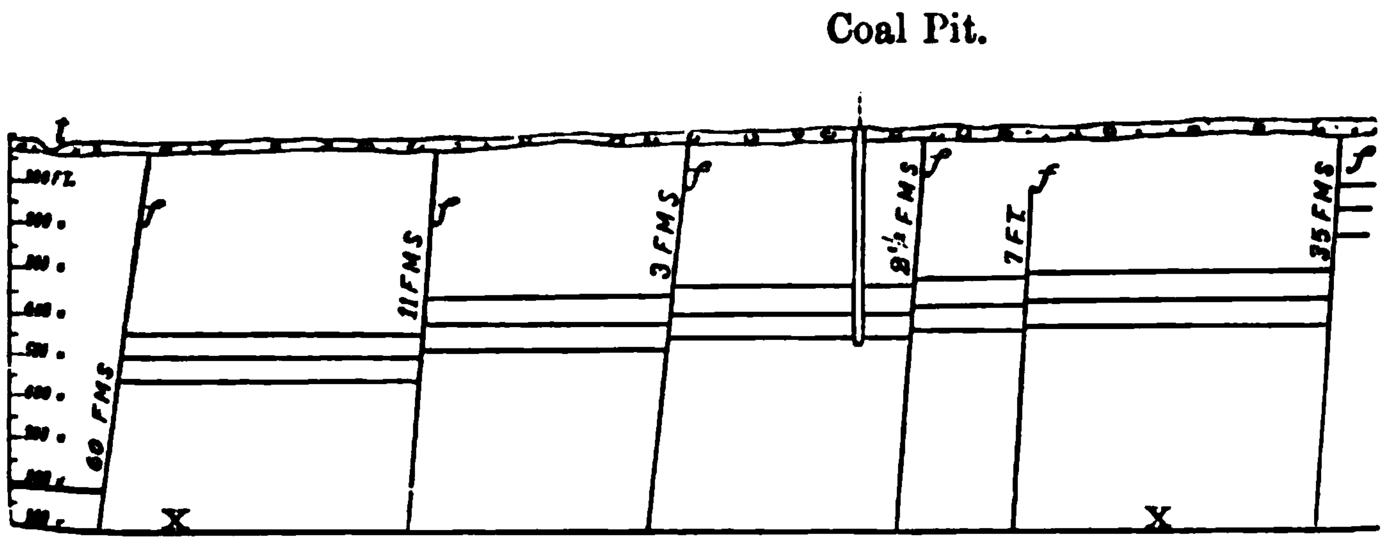


Fig. 53.—Section across Coal-measures at Muirhouse Colliery, near Wishaw (horizontal and vertical scales the same). The horizontal lines represent coal-seams; *f*, faults, the amount of displacement shown in fathoms and feet; X, line 550 ft. below sea-level; *t*, till.

dislocations ever showed at the surface. This is hardly the place to describe the observations which have led me to this conclusion; but I may state that, as a general rule, faults increase in extent downwards and diminish upwards, so that the upper beds are not dislocated to the same extent as the lower seams of the same coal-field. Some of the smaller faults, indeed, die out upwards altogether.

Now we know that hundreds of fathoms of solid strata have been planed off the Lowlands of Scotland since the close of the Carboniferous period, and not a few of the dislocations that now come to the light of day may have died upwards long before the original surface of the Coal-measures was reached. But even if these faults did actually traverse the whole thickness of the strata at the very time the move-

ments of the earth's crust took place, yet they could not have produced any external feature—they could not have been actually visible at the surface. Had it been otherwise—had all the faults which we now see cutting and shifting the strata in every direction shown boldly at the surface—what a very remarkable landscape would have been the result!—straight cliffs intersecting at all angles; here a great parallelogram of strata forming a solid embankment, there a profound and extended chasm fantastically shifted in a hundred places; in one place a long descent, terminating abruptly against the blank wall of a frowning precipice; in another place an inclined plane, rising for a considerable distance, and all of a sudden stopping on the edge of a wall that dropped perpendicularly for 500 or 1,000 ft. Instead of all this wild vagary, we have a softly-outlined country, with its regular valley-system—the direction of the streams never being in any degree influenced by the rock-dislocations, which, as far as the trend of the valleys is concerned, might never have existed.

Judging, therefore, from the contour of the ground in this district, where the direction and amount of the faultings have been so well ascertained, it may be concluded that these dislocations have not been the proximate, nor even the remote cause [1] of the formation of the valleys. Many of the faults may have died out upwards without reaching the original surface, while others that did reach that surface may have displaced the strata so gently, by such gradual creeping, that atmospheric or other superficial denudation may well have kept pace with the movements, and so removed the inequalities as these arose.[2]

[1] It may be well to remind the reader that I am speaking of the Carboniferous areas of the west of Scotland. I am very far from affirming that faults have never in any case given the initial direction to a line of drainage. I could mention a number of instances where they have certainly done so. A good case in point is that of Glen App, in the south of Ayrshire, which coincides with a large fracture. Again, the great north-east and south-west fault that traverses Scotland from the shores of the Firth of Forth to the Irish Sea gives rise in many places to a distinct feature, and streams occasionally follow it for some distance. The Great Glen would also appear to lie in a line of dislocation. Several of the fiords and lake valleys in the north-west of Scotland likewise coincide with faults.

[2] Although these remarks have special reference to Scotland, they have really a much wider application, as many geologists will readily admit. It has been shown again and again, that even in highly-disturbed mountainous districts

Since, then, rock-basins do not occur in these highly faulted districts, it seems idle to speak of such hollows being due to dislocations, unless we are prepared to bring forward some well-proved cases in point. But while no such case has been adduced, geologists have been referred by Sir A. C. Ramsay and others, both at home and abroad, to numerous examples of rock-basins which it can be shown have no connection whatever with gaping fissures and dislocations. Take, for example, that of Loch Doon, or that of Loch Trool in Galloway. In neither of these cases do any shiftings and displacements or cracks and chasms occur, but the beds on the one side exactly correspond with those on the other. One may walk round the lower end of Loch Doon and never have his feet off solid rock all the way. The valley in which it lies cuts right across the strike of the strata, which, as the merest tiro may readily ascertain, are quite continuous.

Nay, more than this, rock-basins are of all sizes; many of them are no larger than an ordinary circus; myriads are a great deal smaller—mere pools; and between this and basins that are square miles in extent we have every gradation. One may wade through or swim across the shallower ones, and satisfy himself that the rock is all solid underneath; and no one indeed has ever ventured to suggest that these smaller hollows are due to fractures. Yet it is just as difficult to account for a rock-basin fifty yards in length as it is to explain the origin of one a hundred times larger. If big ones be caused by fractures, and little ones owe their existence to—something else, where are we to draw the line? —how many square yards are we to be allowed free of fracture?

Some of these objections apply with equal force to another explanation which has been advanced—to this, namely, that the lakes lie in special areas of depression; in other words, that the land has sunk down underneath each lake. It is

the valleys frequently bear no relation, either proximate or remote, to rock dislocations. Thus the late Dr. Hayden and his associates in the geological exploration of the Rocky Mountains have left it on record that the channels of the large rivers in those regions 'have not been determined by special lines of depression or fractures, and that there is no necessary connection between them.' (*Bulletin of the United States Geological and Geographical Survey of the Territories*, vol. ii. p. 208.)

simply incredible that such could have happened. No one will deny that special areas of depression do exist, but to have produced the innumerable lakes of all sizes that stud the surface of alpine countries and many northern regions, the rocky crust of the earth must needs have been in a condition nearly as unresisting as putty. If movements of depression were allowed to explain the existence of a sheet of water like Lake Superior, they would still leave unaccounted for the vast number of smaller lakes that crowd the surface of the northern part of North America, as well as the innumerable lakes of Scotland, Cumberland, Wales, Ireland, Scandinavia, Finland, France, Switzerland, and Northern Italy.

Sir Charles Lyell held that the lake-basins of the two last-named countries owed their origin to a depression of the central region of the Alps, by which the slope of the great valleys was reversed; an explanation which, as Ramsay pointed out, would compel us to assume that the Alps in preglacial times were some 28,000 or 30,000 ft. in height—thus implying an amount of subsequent depression which in itself is improbable, and for which certainly no evidence is forthcoming. He also showed that if the Alpine lake-basins were really produced by a depression of the central region, lakes 'ought also to occur in other valleys that run north and south of the central chain and open on the plains, but which are merely river-courses.' A still stronger objection to Lyell's hypothesis lies in the fact that the trend and outflow of Lakes Geneva and Neuchâtel 'are, roughly, at right angles to those of the other great lakes of Como, Lugano, Maggiore, Orta, Varese, Garda, Thun, Lucerne, Zug, Sempach, Zürich, and Constance; and, to dam up the lakes of Geneva and Neuchâtel, we should require a central depression running north-west between them at right angles to the chain of the Alps, and quite across the Miocene rocks. For this we need,' continued Ramsay, 'a special proof, which has never been attempted; and I do not see but that to produce the whole of the lakes by depression, the supposed great movement must merely resolve itself into a number of minor ones.'

Lyell never, as far as I am aware, applied his hypothesis to account for the rock-basins of Scotland—probably because he knew the configuration of that country too well, and was

aware that no single movement of depression along the watersheds or of upheaval in the lower parts of the valleys would suffice to explain the phenomena. Indeed, when we come to apply his hypothesis to that country, we find that instead of one great movement of upheaval or subsidence we require hundreds of local ones—so very local, indeed, that vertical movements of 1,000 ft. must in many cases have been restricted to an area of only a few square miles. Not only so, but the lakes trend to every point in the compass, necessitating, on Lyell's hypothesis, a manifold series of movements, so confused, opposite, and contradictory withal, that really one feels it much easier to believe in a special depression for each particular rock-basin. More than this: not a few valleys contain two or even three lake-basins, separated from each other by only a few miles, and sometimes by only one mile. What general but 'unequal movement of upheaval or subsidence' will account for these? Is it not plain that if the basins in question owe their origin to 'earth-movements,' there must have been one special upheaval or depression as the case may be for each particular lake. Let anyone try how otherwise he can account, on Sir C. Lyell's hypothesis, for such lakes as Loch Voil and Loch Lubnaig, or the lakes of the Trossachs, or for Loch Lydoch, Loch Rannoch, and Loch Tummel, or for the lakes in Glen Quoich and Glen Garry, or those in Strath Affrick, Glen Cannich, and Strath Monar. Not only do the mountain-valleys often contain more than one lake, but we frequently find that lake-basins are composite, consisting in reality of two or more rock-basins, such as Loch Etive and many other sea-lochs, as I shall presently point out. This, indeed, is a very common characteristic of the lake-basins of Scotland: they have a hummocky, uneven bottom—the rock sometimes rising to the surface in little islets, which are often beautifully glaciated all over—at other times sloping up from considerable depths on one or both sides, so as to form a more or less narrow ridge, which would divide the lake in two were the water to be lowered for only a few feet or fathoms as the case might be. Now, if it be impossible to account, on the hypothesis under review, for the presence of several separate lake-basins in one valley, how can that hypothesis explain the appearance

of the rocky islands, the subaqueous ridges, and the irregular depths that so often characterise one and the same lake-basin?

Another view, which has commended itself to many geologists, is that of earth-movements of a more complex kind than simple movements of depression and upheaval. It is thought probable that rock-basins may have been due to the folding and flexing of the surface which accompanied the formation and subsequent modification of mountains of upheaval. When we study the structure of such a region as the Alps we find that the strata of which the mountains are composed are bent, folded, and contorted, as if they had been subjected to intense lateral pressure. Beds, which we have every reason to believe were deposited in approximately horizontal positions, have been flexed and crumpled up. Not only so, but it has been ascertained that such disturbance of the rocks of a mountain-chain has happened again and again at widely separate intervals of time. It is thought possible, therefore, that long after a mountain-chain had come into existence—after streams and rivers had eroded for themselves valleys that passed outwards from the culminating heights to the adjacent low grounds—earth-movements again took place, and a new series of folds and flexures were formed. These folds, it is supposed, would often trend across the mountain-valleys, and thus give rise to irregular cavities or rock-basins. It seems all very plausible, but no one has yet succeeded in proving that a single rock-basin in any glaciated tract has been formed in this way. That folding and fracturing have taken place along the flanks of many mountain-chains, again and again, is well known. But folding and dislocation would appear to have been so gradually effected that the rivers have been able to cut across the inequalities of surface as fast as these arose. Thus it is a trite observation that rivers are often older than the mountain-ridges which they intersect. The younger folds which have been formed across a valley have evidently risen no faster than the river has worked. Again, many mountain-valleys are crossed by dislocations, on one side of which the rocks have been raised or depressed, as the case may be, for hundreds or even thousands of feet, and yet such rock-displacements have not suc-

ceeded in deflecting the rivers; and obviously for the same reason, namely—that the rate of erosion has equalled or exceeded that of earth-movement. If it had been otherwise —if rivers, as a rule, had not worked as fast or faster than foldings and rock-displacements were effected, lake-basins ought to have abounded in all mountain-tracts throughout the world, from circumpolar to equatorial regions. But, as is well known, they are of the rarest possible occurrence amongst the mountains of warm and tropical countries, while they are conspicuously abundant in every region which has formerly supported snow-fields and glaciers. Are we to suppose, then, that the torrents, and streams, and rivers in non-glaciated mountain-tracts are better workers than those in our own and other ice-worn lands? If the mountain-streams in warm countries have succeeded in carving their way across the backs of rising folds, why should the rivers of the Alps and all glaciated mountain-chains have failed to do so? But the notion that the lakes of the Alpine lands owe their origin to flexures crossing the lower ends of the mountain-valleys is a mere pious opinion—frequently expressed and strongly asserted, but never supported by any proofs that will bear critical examination.

If the hypothesis under review breaks down when applied to explain the origin of the great lakes of so young a mountain-chain as the Alps, it fails even more conspicuously to account for the lakes of our own country or those of Scandinavia and Finland. It is quite certain that all the folding and flexing which the rocks of our Highlands have experienced was completed long ages before the Alpine ranges came into existence. It is simply absurd to suppose that any rock-basins then formed could possibly have persisted to the present. Not a single rock-basin in our islands or in northern Europe can be shown to owe its origin directly to flexing or folding of any kind. In a word, it is just as impossible to account for the lakes of those highly glaciated tracts by means of rock-foldings as by the childish supposition that they owe their origin to unequal movements of upheaval and subsidence. Here and there in our north-west Highlands and in a few cases in Scandinavia lake-basins coincide more or less closely with lines of fracture and rock-displacement.

It would be strange, indeed, if in regions where the rocks are so highly disturbed and confused, valleys should not occasionally coincide with faults. Those faults were lines of weakness which, in ages long prior to the glacial period, determined the direction of the surface-drainage, and thus eventually gave rise to straight river-valleys. Later on the glaciers only followed the lead of the rivers and deepened the depressions into which they flowed.

In a recent very interesting article, Dr. A. R. Wallace has subjected the hypothesis we have just been considering to a destructive criticism. 'Nothing,' he remarks, 'is more easy, and nothing seems at first sight more plausible, than to allege these "earth-movements" to account for any lake whose origin may be under discussion. But it ceases to be either easy or plausible when we consider the great number of the lakes to be accounted for, their remarkable positions and groupings, and their great depths. We must postulate these movements, all about the same time, in every part of the Highlands of Scotland, everywhere in the Lake district, and on both sides of the Alps. Then, again, the movements must have been of greater extent just where we can prove the glaciation to have been most severe. It produced lakes from 100 to 270 ft. deep in Cumberland and Westmoreland; in Scotland, where the ice was much thicker, the lakes are from over 300 to over 1,000 ft. deep; while in the Alps of Switzerland and North Italy, with its vast glaciers and ice-sheets, many are over 1,000 ft. and one reaches the enormous depth of 2,500 ft. It may be said that the depth is in proportion to the height of the mountains; but in equally high mountains that have not been glaciated there are no lakes, so this cannot be the true explanation. One more remarkable coincidence must, however, be pointed out. The two largest Swiss lakes—those of Geneva and Constance—are situated just where the two greatest West European rivers, the Rhone and the Rhine, get beyond the mountain-ranges; while on the south, one of the largest and by far the deepest of the lakes—Lago Maggiore—collected into its basin the glacier-streams from a hundred miles of the high Alps, extending from Monte Rosa on the west to the peaks above San Bernardino on the east. Throughout this great

curve of snowy peaks the streams converge, with an average length of only 30 miles, to unite in a valley only 646 ft. above the sea-level. No such remarkable concentration of valleys is to be found anywhere else in the Alps, and no other lake reaches to nearly so great a depth. On the theory of glacial erosion we have here cause and effect: on that of earth-movements we have another mere coincidence added to the long series already noticed. The depth of over 2,500 ft. undoubtedly seems enormous, but that depth exists just at the point where the two great valleys which have collected the converging streams, above referred to, unite together.'

Dr. Wallace has further pointed out that the earth-movement hypothesis 'does not attempt to explain that wonderful absence of valley-lakes from all the mountain-regions of the world except those which have been highly glaciated. . . . We are asked to believe that in the period immediately preceding the Glacial epoch—say in the Newer Pliocene period—earth-movements of a nature to produce deep lakes occurred in every mountain-range without exception that was about to be subject to severe glaciation, and not only so, but occurred on both sides of each range, as in the Alps, or all round a mountain-range, as in our Lake district, or in every part of a complex mountain-region, as in Scotland from the Firth of Clyde to the extreme north coast—all in this very limited period of geological time. We are further asked to believe that during the whole period from the commencement of the Ice Age to our own day such earth-movements have never produced a single group of valley-lakes in any one of the countless mountain-ranges and hilly regions throughout the whole of the very much more extensive non-glaciated regions of the globe. This appears to me to be simply incredible.'[1]

If, then, all the 'explanations' discussed in preceding paragraphs be rejected, we have only one agent left which can possibly account for the origin of rock-basins, and that, as already indicated, is *ice*. Ramsay pointed out, in the first place, that these remarkable lakes abound in every region which is known to have been subjected during the glacial period to the grinding action of glaciers; while conversely, in tropical areas or such countries as have not supported

[1] *The Fortnightly Review*, December 1893.

glaciers, true rock-basins do not occur. Thus, if we exclude the great African lakes, of which we know too little as yet to justify us in coming to any definite conclusion in regard to the mode of their formation, and if we also put aside lagoons and crater-lakes and other lacustrine hollows in volcanic regions some of which owe their origin to local depressions, while others may be due to the damming-up of valleys by lava, &c., we shall find that in our hemisphere rock-basins increase in number as we pass from south to north, and are always specially abundant in mountainous districts. And this peculiar distribution Ramsay accounted for by the bold suggestion that the basins have been ground out by glaciers.

He shows that the erosive action of a glacier must necessarily be less at the lower end, where the ice is comparatively thin, than farther up the valley, where the ice attains a much greater thickness. Obviously, then, were a glacier to continue to flow for a sufficient length of time, down a relatively flat-bottomed valley, this unequal pressure upon the underlying rock would produce some effect; erosion would be more intense where the ice was thick than where it was thin, and thus a rock-basin would eventually be formed.

Take the case of a glacier creeping down an alpine valley and spreading itself out upon the low ground at the foot of the mountains. Let us suppose that, in the upper part of its course, the incline down which it moves is greater than the slope of the lower reaches of the valley. When the glacier attains the more gently inclined part of its course, it is evident that its flow must be retarded, and there will therefore be a tendency in the ice to accumulate or heap up. Now we know that the pressure of a body in motion upon any given surface varies with the degree at which that surface is inclined; as the inclination decreases the pressure increases. It follows from this that when the glacier leaves the steeper part of its course, and begins to creep down the gentler slope beyond, it will press with greater force upon its rocky bed, and this increased pressure will be further intensified by the greater thickness of the accumulated ice. But as our glacier continues to flow, it gradually loses in bulk, its rate of motion at the same time diminishes,[1] and thus its erosive power

[1] *La Névé de Justedal et ses Glaciers*, by C. de Seue.

becomes weaker and weaker. The result of all this is the formation of a rock-basin, the deeper portion of which lies towards the upper end, just where the grinding force of the glacier is greatest.

Such is the effect we might naturally expect glacial action to produce. When we turn to the rock-basins in our own country, we find these in the very positions which, theoretically, they might have been expected to occupy. And not only so, but they almost invariably reach their greatest depths towards the upper end, shallowing away gradually down the valley. Cases in point are Loch Doon, Loch Trool, and numerous other rock-basins amongst the Carrick and Galloway mountains. One of the best examples of a rock-basin is furnished by Loch Lomond, a map and sections of which, drawn on a true scale, will be found in the Appendix. No fault or dislocation of the solid strata is known to cross the area occupied by the Loch; but Mr. R. L. Jack detected one that crosses below the foot of the loch, passing through Tullichewan Castle on the west side and Haldane's Mill on the east; and the downthrow side of this fault is to the south —a clear proof, if such were needed, that faulting and unequal subsidences of the rock have had nothing whatever to do with the formation of the great hollow.

Another striking circumstance in connection with Scottish lakes is this—their dimensions are almost always proportionate to the extent of the drainage-system in which they occur. If the valley in which any particular rock-bound lake appears should be an important one, draining a wide tract of elevated ground, the lake is sure to be long and deep; if the valley be of inconsiderable extent, the rock-basin it happens to contain is certain to be proportionately unimportant. In other words, where large glaciers are known to have existed, we find large rock-basins, while in valleys which have been occupied by inconsiderable glaciers, the rock-basins are small.[1]

[1] Dr. Wallace, in the article already cited, has pointed out certain criteria by which we may distinguish lakes which occupy glacially eroded basins from lakes lying in valleys which have not been thus modified by glacial action. He shows that all glacially eroded basins 'present rather steeply-sloping sides with broad, rounded, or nearly level bottoms of saucer-shape; such as are certainly not characteristic of sub-aërial valley-bottoms, but which are exactly what we might expect as the ultimate result of thousands of years of ice-grinding.' Lake-

These remarks on Scottish rock-basins would be incomplete if no reference were made to the fiords or sea-lochs so abundantly developed along the west coast. The hollows occupied by these arms of the sea are simply submarine continuations of land-valleys, which, as everyone knows, stretch into the country for a less or greater distance from the head of every fiord.

If the reader will glance at a map of Scotland, he will observe that while fresh-water lakes are plentifully present on the eastern slopes of the great watershed that runs from the head of Loch Shin to the hills above Loch Linnhe, there are comparatively few on the other side, but we have great sea-lochs instead. Now each of these submerged land-valleys contains at least one rock-basin, so that if the land were only to be elevated sufficiently, we should find in that region an exact counterpart of the appearances that present themselves on the eastern slopes of the watershed, namely, deep mountain-glens with rock-bound lakes.

The Admiralty charts are excellent maps of the sea-bottom, and afford clear and definite ideas of its physical features. The tracings given are taken from the reduced Admiralty chart of the west coast of Scotland. One of these

basins of this kind never present peculiarities of contour which are not unfrequent in mountain valleys, such as ravine-like river channels and jutting rocky promontories. Again, 'Alpine lake-bottoms, whether large or small, frequently consist of two or more distinct basins, a feature which could not occur in lakes due to submergence, unless there were two or more points of flexure for each depression—a thing highly improbable in the larger lakes, and almost impossible in the smaller.' Once more: 'in most river-valleys through a hilly or mountainous country, outside of the glaciated districts, the tributary streams entering more or less at right angles to the main valley are seen to occupy small valleys of their own, which usually open out for a short distance at the same level before joining the main valley. . . . Now if in such a valley we could mark out a contour-line 200, 300, or 500 ft. above the level of the main stream, we should see that line continually turning up each side valley or ravine till it reached the given level at which to cross the tributary stream, and then turning back to the main valley. The contour-line would thus form a series of notches or loops of greater or less depth at every tributary stream with its entering valley or deeply-cut ravine, and if the main valley were filled with water this line would mark out the margin of the lake.' Now the valley-lakes in glaciated districts show a very different contour. In these the water does not form inlets up the inflowing streams; on the contrary, the latter form an even junction with the lake-margin, just as they would do if flowing into a river. This is characteristic of every rock-basin in this and other glaciated lands. 'On looking at the maps of any of these lakes, one cannot but see that the lake *surface*, not the lake *bottom*, represents approximately the level of the preglacial valley, and that the lateral streams and torrents enter the lake in the way they do because they could only erode their channels down to the level of the old valley before the ice overwhelmed it.'

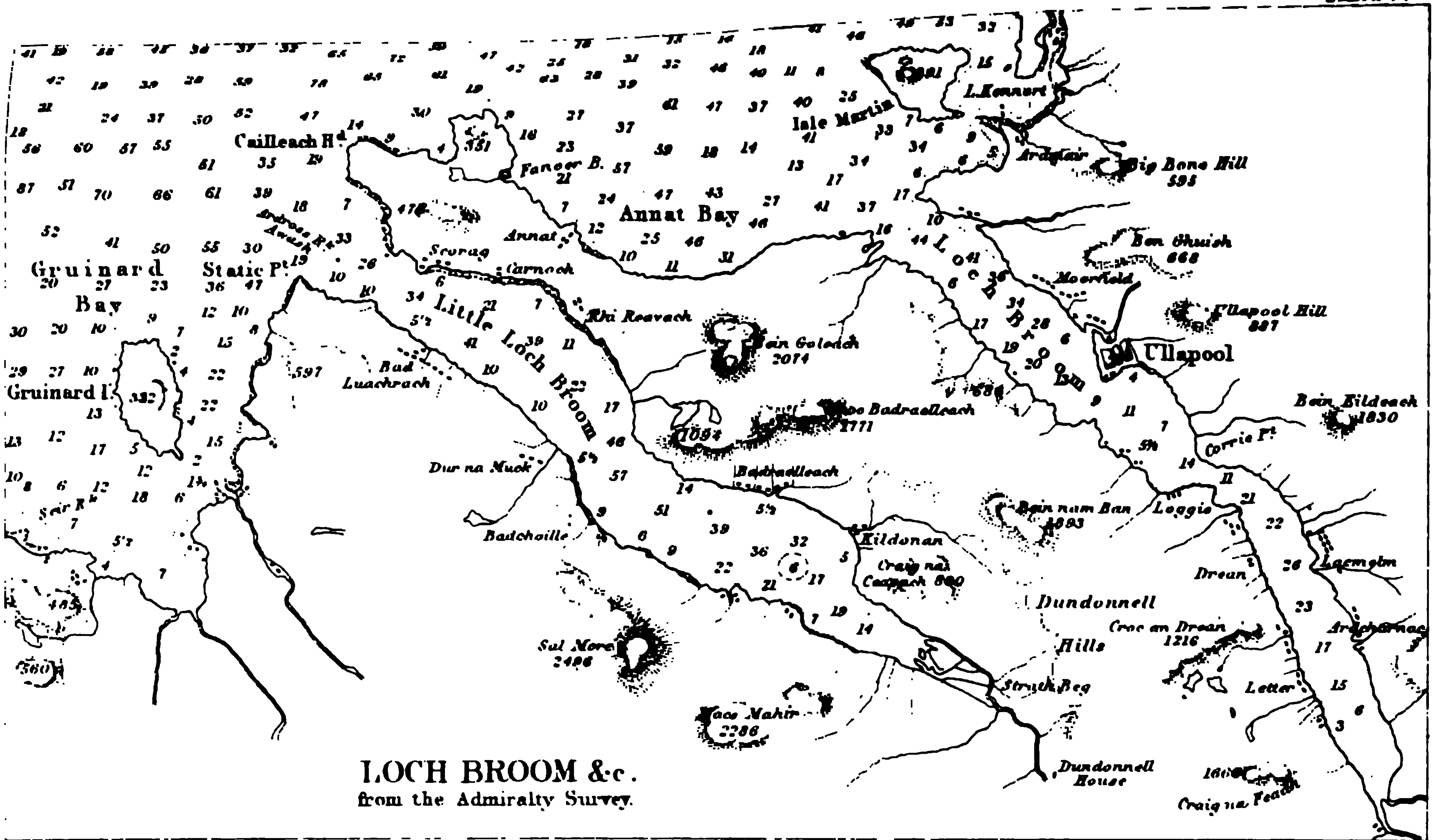
Fig. 54. Loch Doon (upper reach); a Rock-Basin surrounded by *roches moutonnées*. (B. N. Peach.)

(Plate V.) shows Loch Broom, and Little Loch Broom, with Gruinard Bay. This part of the coast has been selected for no other reason than simply because it happens to come nicely within the compass of one of these pages. Almost any other sea-loch would have served my purpose equally well—some of them, indeed, would have done better, as for example, Loch Long, Loch Fyne, or Loch Sunart.

It will be observed, upon glancing at the chart, that the upper reach of Loch Broom, between Corrie Point and the head of the loch, rests in a distinct basin, the lower lip of the basin opposite Corrie being reached at a depth of 11 fathoms, and its deepest part, 26 fathoms, occurring near Lacmelm. There appears to be a second basin between Corrie Point and the mouth of the loch, but it is not so well marked. Little Loch Broom, however, is an admirable example. At the mouth of this loch the underlying rock comes actually to the surface in Ardross Rock, and between this point and the shores we have the maximum depths of 10 and 26 fathoms respectively. Yet the soundings half-way up the loch show a depth of no less than 57 fathoms. Beyond the mouth of the loch the water deepens somewhat gradually until a depth of 119 fathoms is attained, beyond which it shallows again to 34 fathoms. Now it is worthy of remark that no part of the North Minch, on which Gruinard Bay opens, is anywhere deeper than some 50 or 60 fathoms, except immediately opposite the mouths of the great sea-lochs that open out from the mountain-valleys of Harris and Lewis, and the mainland. The 100-fathom line is only reached when we get beyond the Outer Hebrides altogether. Yet it is no uncommon thing to get greater depths than this in many of the sea-lochs and sounds. In the Inner Sound of Raasay, for example, we find depths of 100, 128, and even in one place of 138 fathoms! (See Plate VI.) Thus, were Scotland to be lifted out of the sea for 100 fathoms, all the islands would be connected with the mainland, and numerous lakes would exist to mark the sites of the sea-lochs, one of which, lying between Raasay and Ross-shire, would reach as much as 528 ft. in depth.[1]

Here then is the singular fact that the deepest portions of the Scottish seas lie close in shore ; nor in the majority of cases

[1] See Map showing Physiography of Western Scotland, Plate VIII.



LOCH BROOM &c.
from the Admiralty Survey.

Scale of English Miles
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London: Edward Stanford, 26 & 27, Cockspur St. Charing Cross, S.W.

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Scale of English Miles

0 1 2 3 4 5 10

London: Edward Stanford, 26 & 27, Cockspur St., Charing Cross, S.W.

can there be any doubt whatever that these deep submarine hollows are true rock-basins. In many cases, indeed, the soundings actually prove this. Still some may think that since we do not actually see the lower lips of these basins, it is at least doubtful whether they really consist of rock. Might not the lower lips be formed of mud or sand? We know that the sea has the power of heaping up banks of these materials across the mouths of estuaries; might not this be the explanation of the basins in our sea-lochs? Now there are many reasons which could be given to show why it is in the highest degree improbable that banks of the kind required would always accumulate in such places. But it is not necessary to go into this question, for it is quite evident, upon a little reflection, that even if the sea had the power to heap up, and were now actually engaged in heaping up banks across the mouth of every sea-loch on the coast, still this would not help us to explain the matter any better. For, assuming this to be the case, we should be compelled to admit, first, that the beds of all the sea-lochs did at one time fall away gradually from their present extreme depth up to and even far beyond the 100-fathom line; in other words, that the floor of the sea sloped persistently outwards from the greatest depths reached by the fiords. So that if the land had then been elevated above the waves, there would have appeared mountain-valleys containing no lakes, but showing rivers that flowed on uninterruptedly up to and even far beyond the edge of what is now termed the Scottish submarine plateau. But this plateau is not known to be breached by any such profound submarine valleys. Then, in the second place, we should be forced to hold the extravagant belief that the sea had filled up all these deep hollows with accumulations of sediment varying in thickness from 30 or 40 to considerably more than 100 fathoms, but had left the shoreward portions of its bed pretty much as they were before submergence ensued; that, in short, only the lower reaches of the submarine valleys had been silted up, the platform of sand and mud stopping abruptly opposite the mouths of the sea-lochs, and not a few of the sounds! Into such absurdities do we land ourselves if the rock-bound nature of the basins in the sea-lochs be denied.

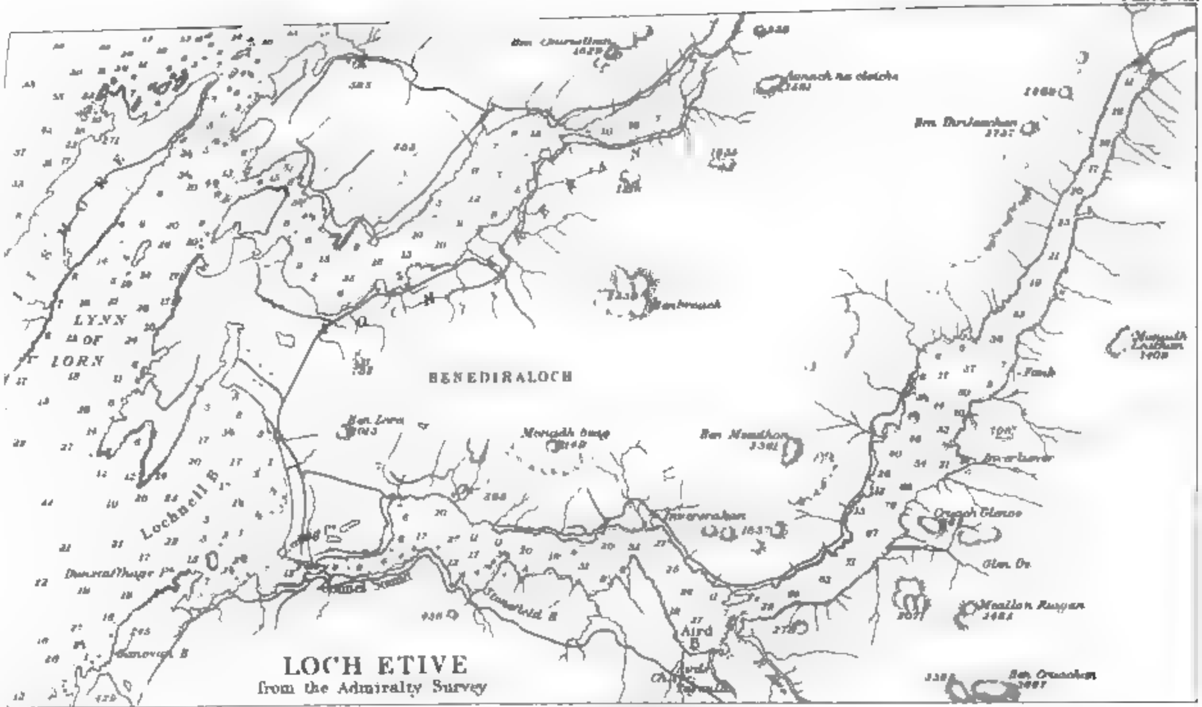
Fortunately, however, there is at least one sea-loch of the

rock-bound character of which we have ocular demonstration. I refer to Loch Etive. This loch, as the chart (Plate VII.) will show, contains two basins, the lower one of which extends from Connel Ferry to near Taynuilt, the upper one from this place to the head of the loch. At Connel Ferry the passage is very narrow, and the rock so near the surface that at half-tide the water rushes over the reef with the roar of a cataract. The sight of the seething white water will, I should think, be enough to convince even the most sceptical that, above the ferry, Loch Etive is a true rock-basin. It will be observed that the greatest depth attained in the lower basin is 35 fathoms; in the upper basin we have a depth of not less than 76 fathoms. Here then we have a double rock-basin, the bottom of which is rather more than 400 ft. deeper than its lower lip.

Now while such deep submarine rock-basins can be traced in all or nearly all the sea-lochs, it is remarkable that no such basins occur opposite a low flat stretch of country. For example, along the western shores of Lewis, in which part of the island there are no deep valleys, we find that the sea-bottom inclines very gradually outward; and the same is the case off the low-lying districts on the eastern sea-board of Scotland. There seems to be an obvious connection, therefore, between submarine rock-basins and sea-lochs, just as there certainly is between sea-lochs and mountain-valleys. Nor, if we admit that rock-basins, filled with fresh water, have been ground out by glaciers, can we, as I think, escape the conclusion that the submerged rock-basins have had precisely the same origin; for the presence of the sea is a mere accident. We know for a fact that all those sea-lochs were once filled to overflowing with ice, and rock-basins occur just in those places where from theoretical considerations they ought to appear. An attentive examination of the physical features of the fiords, and a careful scrutiny of the Admiralty charts, will show that whenever the opposite shores[1] of a fiord approach each other so as well-nigh to separate the water into two separate sheets, two distinct rock-basins are

[1] I refer, of course, to promontories of solid rock. Where a lateral stream enters a fiord, a spit of low land frequently projects for some distance into the water, but that is a very different matter.

PLATE VII.



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Scale of English Miles

0 1 2 3 4 5

London: Edward Stanford, 26 & 27, Cockspur St. Charing Cross S.W.

almost invariably the result. This appearance is well explained by the erosion theory, but is inexplicable otherwise. When glacier-ice filled such a fiord, it would be strangled in the narrow pass, and the motion of the ice advancing from behind would be impeded. Hence there would be a heaping up of the glacier, and intensified pressure upon the rocky bed would produce its natural effect—increased erosion.

At the same time, not a few double rock-basins may have been deepened in another way. During the advance of the glaciers there may have been pauses; each pause, if of sufficient duration, being marked by the formation of rock-basins. When, again, the glaciers began to retire, the same set of circumstances might well recur—pauses might take place, and basins be again deepened. Moreover, owing to the nature of the ground and the character of the drainage-system, one may be quite sure that a glacier would tarry much longer in some reaches of its valley than in others. Hence we might naturally expect the valleys often to contain more rock-basins than one. If the larger fresh-water lakes were drained, we should in all probability find that some of them would show separate basins, analogous in a measure to the upper and lower basins of Loch Torridon, Loch Cairn-Bahn, and others. Even as it is, however, many valleys do contain more than one lake. Good examples occur in the region of the Trossachs. Again, in the valley of the Tummel we have Loch Lydoch, Loch Rannoch, and Loch Tummel. Farther north, in the valley of the Conan, we come upon the wild Loch Fannich and, lower down, Loch Luichart. The valley of the Doon, in Ayrshire, contains the Loch of the same name and Bogton Loch, which last, although now much silted up and of little extent, is yet proved to be a rock-basin, from the fact that the soft watery mud of its alluvium broke into some coal-workings in the neighbourhood, at a depth considerably below that of the rock which comes to the surface and crosses the valley a mile or so farther down.

So long a time, indeed, has passed since the glaciers vacated the valleys, that streams and rivers, by carrying down and depositing gravel, sand, and silt, have often obscured the original rock-bound character of the lake-basins, and in several cases have even entirely obliterated them, so that we find

broad flat meadows where lakes formerly existed. As an instance of a partially obliterated rock-basin, I may refer to St. Mary's Loch, in the south of Scotland, the depth of which has been ascertained to be at least 120 ft. At its outlet the whole valley is paved with gravel, but a series of borings made across the bottom of the valley at this place struck the rock at depths varying from 24 to 53 ft. The present bed of the lake is therefore 67 ft. at least lower than the lip of the buried rock at the point of outlet; what thickness of superficial materials may be lying upon the rocky bed of the lake has not been ascertained.[1]

Of rock-basins completely obliterated, many examples might be given. There is one at the head of the Manor Water, in Peeblesshire. Another fine instance occurs in the valley of the Talla (same county), where an ancient lake once occupied the whole bottom of the valley from Talla Linnfoots for nearly two miles down. The higher valleys of the Cheviot Hills afford examples of the same phenomena. But, as might have been expected, the rock-basins that are so silted up are usually of small extent.

From the foregoing discussion it will be gathered that the fresh-water lakes of Scotland form three more or less well-marked groups which, according to their geographical position, may be described as Lowland lakes, Mountain-valley lakes, and Corrie or Cirque lakes. The lakes of the first group are met with most abundantly, scattered over the surface of the Lowlands, at and below the level of 600 ft. above the sea. Some of these are rock-basins, but the majority owe their origin to the irregular distribution of glacial deposits. Hence, sometimes they lie partly in drift, partly in rock, or they may be wholly surrounded by glacial accumulation. Mountain-valley lakes almost invariably occupy rock-basins, and the same is the case with Corrie lakes, although some of the latter appear to be dammed by morainic matter and fallen rock-masses.

The reader must not confound the question of the glacial origin of rock-basins with that of the origin of valleys and cirques. Our mountain-valleys were in existence long before the ice period, and many of them doubtless headed in cirques,

[1] These data I obtained from Messrs. A. and A. Leslie, C.E., Edinburgh.

before any glacier appeared in our country. Cirques are of common occurrence in mountain-regions in other lands which we have no reason to believe were ever glaciated, but in such countries neither valleys nor cirques contain rock-basins. The cirques in question are usually somewhat funnel-shaped —they resemble the section of an inverted hollow cone, but never show the circular saucer-shaped, basin-like bottom which is the essential character of a cirque as modified by glacial action. It was doubtless the form of a cirque—the precipitous sides of which converge to a central point—which enabled the ice that subsequently filled it to concentrate its erosive energy upon that point and so eventually to grind out a basin. So long a time has elapsed since the disappearance of our old glaciers, that many corrie lakes have been filled up or drained by the cutting down of their outlets. And it needs little observation to convince one that this fate must eventually overtake every lake in the country.

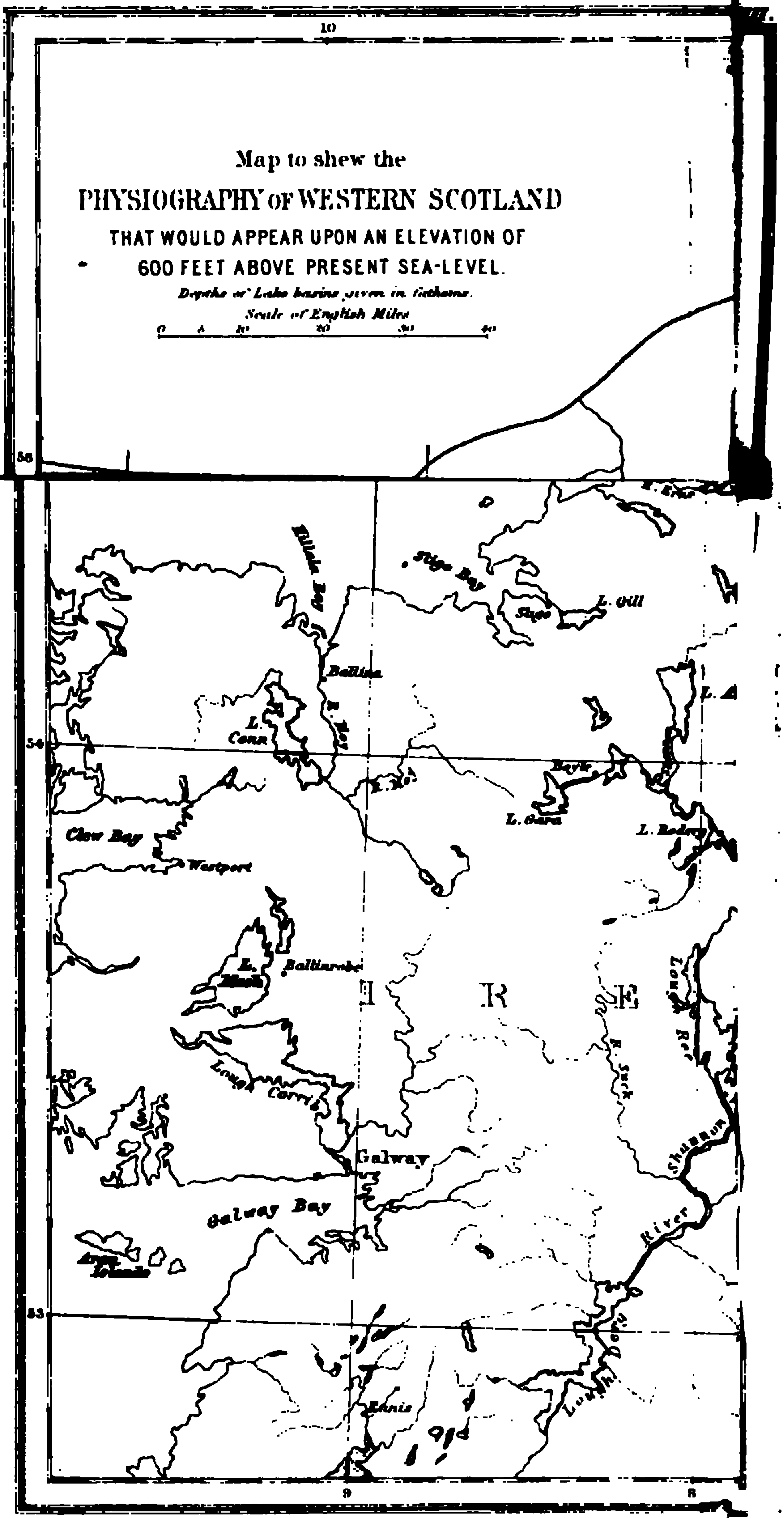
CHAPTER XIX.

ROCK-BASINS OF SCOTLAND—*continued.*

Fiords plentiful along west coast, but not so on east coast—Depths in the Firths of east coast—Examples of *fiord-basins*—Examples of *deflection-basins*—Union of the two groups; examples—Classification of rock-basins.

MANY years ago I was struck with the fact that the deeper parts of the Scottish seas appeared precisely in those places where a glacialist might readily have expected to find them. Not only did deep rock-basins occur in all the sea-lochs or fiords, but they also made their appearance again and again off the coasts of many islands in such positions as could not but be highly suggestive. In connection with these facts it was also singular to observe that, while deep submarine hollows were so abundantly developed along the western shores of Scotland, they were almost entirely wanting in the corresponding latitudes on the other side of the island. And then, one could not fail to notice that, with the exception of the Firths of Forth, Tay, Inverness, Cromarty, and Dornoch, no fiord-valleys open out upon the German Ocean, and no such islands as the Inner and Outer Hebrides appear on the east coast. Fiord-valleys and islands abound in the west, and there rock-basins are numerous; hardly any fiord-valleys or islands exist in the east, and there submarine hollows are rarely to be found. As far as I can make out from the Admiralty charts, only one deep submarine basin occurs along the whole stretch of coast-line between Duncansby Head and Berwick, and that is in the upper reaches of the Firth of Forth, between St. Margaret's Hope and a point east of Kinghorn and north-east of Inch Keith. The hollow is a long narrow trench, gradually opening out as it shallows to the north-east of Inch Keith. It is deepest near Inch

Coast



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e, where its bottom is 246 ft. below the surface of the r 186 ft. lower than the lip of the trench. It shallows ig east, but deepens again to 168 ft. between Inch Colm ie Oxcars Rocks, shallowing once more, and again deep- to 138 ft. before it finally shelves away. It is certain, ver, that this basin must at one time have been more sive. Immense quantities of silt and sand are borne into the estuary of the Forth, and great banks of sand aud have accumulated, especially in the upper reaches e estuary. There cannot be much doubt, therefore, that ibmarine hollow has been greatly silted up.[1]

o hollow so deep as this appears in any of the other that open into the German Ocean, but each is charac- d by the presence of great banks of sand and mud, a in many cases impede navigation. In the Firth of the mud-banks are specially noticeable; above Dundee 'irth at low-water shows little more than a series of banks, with winding water-lanes; and below Dundee, ie mouth of the estuary, the mud and sand are pushing eaward, so as to form a well-defined submarine delta. hort, it is evident that all the firths on the east side of sland have been and are still being gradually silted up. we may still trace elongated hollows in these firths. e is one 48 ft. deep opposite Broughty Ferry; two occur eauly Loch, 108 ft. and 72 ft. deep respectively; Cro- y Frith is 120 ft. deeper than the sea outside, and ugh Dornoch Frith is very shallow, it is still 36 ft. deep e the Bar, which is only 12 ft. below the sea.

'o return to the west coast: I would first direct the er's attention to the general slope of the sea-bottom, as sented upon the map (Plate VIII.), which has been re- d for me by my friend Mr. R. L. Jack from the Admiralty ts of the west coast of Scotland.[2] (See also Plate IV.) ill be observed that (putting rock-basins for the moment of account) the bottom of the sea in the North Minch

[1] n the borings made for the Forth Bridge, a mile above Blackness Castle, ud and clay lying upon the bottom of the Frith were found to vary in iess from 90 up to 176 ft.

[2] *Scotland, West Coast*, from surveys by Captains Robinson, Otter, and Bedford, Commanders Wood, Thomas, and other officers; *Ireland, East*, from surveys by Captain Beechey and others. Nos. 2,365 and 1,824.

falls away towards the north, a river being inserted to show the direction the drainage would take were an elevation of the whole west coast, to the extent of 600 ft., to supervene. Between the north end of Skye and the Shiant Isles the soundings indicate the existence of a ridge which would form a low watershed between the country of the North Minch and that lying to the south. The configuration of this latter, however, is exceedingly irregular, and it is difficült to ascertain from the charts in what direction the lakes in the Little Minch would drain; most likely, however, it would be southwest into the large lake which is represented as sweeping from South Uist round Barra Head, and sending a river out to the sea. West from the island of Islay another stream is inserted to show the slope of the land in that direction. It must not be supposed that these rivers are put down at random. The charts have been closely followed, and it is believed that the lines indicated are as near as possible those that would be taken by the streams and rivers upon an elevation of 600 ft. A greater number might have been inserted, but it was thought better to give only such as would suffice to indicate the general slope of the sea-bottom.

A glance at the map will show that the chief submarine basins occupy certain well-defined positions, and form two distinct groups. The first group embraces what may be termed *fiord-basins*. Enough has been said in the preceding chapter regarding the rock-hollows which are known to occur in our sea-lochs. These of course agree in direction with the sea-lochs, with which they are sometimes almost co-extensive, as in the case of Loch Fyne; or entirely so, as in the case of Loch Etive. But an examination of the Admiralty charts proves the existence of numerous submarine basins which lie beyond the sea-lochs, and run parallel to the course of sounds, channels, and straits. As examples we may take the basins of Raasay Sound, the Inner Sound, Sleat Sound, the Passage of Tiree, the Frith of Lorn, and Jura Sound. Now, these basins occur in what are simply the continuations of fiord-valleys. If the land were elevated for 600 ft. it would be seen that all these 'Sounds' and 'Passages' only formed the lower reaches of mountain-valleys. The Sound of Jura, for example, would appear as a great mountain-valley con-

tinuous with that of Loch Craignish. In the same manner, Sleat Sound would be continuous with the valley that now holds Lochs Alsh and Hourn. And each of these valleys, as the map shows, would contain deep fresh-water lakes. We may therefore define the *fiord-basins* as those hollows which occupy the beds of, and extend in the same direction as, submerged mountain-valleys. They therefore follow the general slope of the sea-bottom, as the map itself sufficiently indicates.

Reasons have already been given for concluding that the rock-basins in our sea-lochs were ground out by glaciers which once filled all those now submerged land-valleys. We may next examine one or two of the rock-basins that occur in the sounds and straits, for the purpose of ascertaining whether appearances are such as to indicate a similar origin for them.

The map represents a large lake as occupying the sites of Raasay Sound and the Inner Sound, and stretching northwards to a point opposite Loch Broom. This is one of the deepest areas on the west coast of Scotland, the lip of the submerged basin being 50 fathoms, and its deepest part no less than 138 fathoms below the surface of the sea. Were the land to be sufficiently elevated, we should have here a fresh-water lake 88 fathoms, or 528 ft. in depth; so that, even were the land to be upheaved for 600 ft., the bottom of the Raasay Lake would still be 38 fathoms below the level of the sea. Its deepest part trends along the east coasts of Raasay and Rona, and it shallows gradually away towards the north; that is to say, it is deepest where the channel is narrow—while, on the contrary, it begins to shallow as it expands into the North Minch. Now, if we examine the maps (Plates I. and IV.), we shall find that this large submerged basin was at one time occupied by a massive glacier that flowed in precisely the same direction as the trend of the basin itself, that is towards the north. Note further, that the direction of glaciation in Lochs Carron and Kishorn shows that ice once filled those lochs and spread over the low grounds of Skye between Broadford and Loch Eishart, where also it has left marks of its passage. This was doubtless at the same time that Raasay Sound and the Inner Sound were

choked with glacier masses streaming outwards from Skye, Gairloch, Loch Torridon, and Loch Carron itself. For the reasons given in the preceding chapter, the erosion produced by this ice would be most excessive where the latter was strangled or compressed and heaped up. Consequently, we find that it is between the mainland and the islands of Raasay and Rona that the basin attains its greatest depth. As the glacier crept out into the Minch it had room to expand, and therefore its erosive action became weaker in that direction.

I have selected for illustration one of the simplest cases. When we come to examine other fiord-basins, we not infrequently find that they are mixed up with a set of basins which cannot be said to coincide with mountain-valleys. These form our second group, one or two simple examples of which I shall describe first, and thereafter point out how the two groups sometimes coalesce.

The basins of the second group not infrequently extend at right angles to the trend of the fiord-basins, and are most typically developed along the inner shores of islands, especially when these are placed opposite the mouths of sounds and sea-lochs. As good examples, I may mention the great series of basins that stretch along the inner shores of the Outer Hebrides. For reasons which will be given presently, these may be conveniently termed *deflection-basins.*

A good example of a deflection-basin will be observed circling round the north of Rum. It reaches its greatest depth opposite Loch Eishart, where the depression on the sea-bottom is as much as 74 fathoms, the bottom of the basin being 139 fathoms from the surface. Now it is certain that this is precisely where, during the climax of glaciation, there would be immense erosion caused by the stemming of the ice that streamed out from the Coolin Mountains and Loch Eishart. Note how the basin is continued into Canna Sound, where it attains a depth of more than 50 fathoms, its bottom being 130 fathoms below the surface of the sea. Between Eigg and Rum we encounter a similar excavation which has an actual depth of not less than 48 fathoms, although the bed of the sea is only 86 to 88 fathoms deep at that place. This latter basin is separated from the one lying

north of Rum, but they were doubtless formed by the same glacier-mass, which, splitting upon Rum, must have poured round that island, and exerted vigorous erosive power in the channels that separate Rum from Eigg and Canna.

Let us take another example. Mention has already been made of the deep basin that extends north from the Inner Sound into the North Minch, where it ends against the Shiant Isles and a bank known to fishermen as the Shiant East Bank. It will be observed that facing the end of the Raasay basin (which is a fiord-basin), another deep submarine hollow extends itself along the shore of the Long Island, opposite Loch Shell. This, there can be no doubt, belongs to our group of deflection-basins. When the ice which ploughed out the Raasay basin extended so far as to reach the Shiant East Bank, it would have a tendency to creep along the general slope of what now forms the bed of the sea; that is, it would trend towards the north. But as the whole of the North Minch became at the same time choked with glaciers descending from the glens of Sutherland, it is evident that its passage in that direction would necessarily be blocked. It would therefore be compelled to abut upon Lewis. Now we know that the ice which filled the North Minch attained so great a thickness that its upper strata were enabled to overflow the whole of Lewis from south-east to north-west, to a height of 1,600 ft., or thereabout. This is shown by the abundant traces of glacial erosion all over the island. But while the upper strata of ice were grinding across Lewis, there would necessarily be an 'undertow' trending along the coast both to the north-east and the south-west. The greatest pressure would be exerted close in shore, where the high ground opposed the direct passage of the ice; and hence deflection-basins would be ground out in such places. The process, indeed, would be precisely the same as in the case of Rum. The map (Plate VIII.) represents a whole series of similar basins, extending along the inner margin of the Outer Hebrides. None of these is a fiord-basin, but off the mouth of Loch Dunvegan, in Skye, there appears to be a union of basins belonging to both groups. South of Benbecula, however, the hollows which trend along the coast of the Hebrides seem certainly to be deflection-

basins. This will become apparent when we reflect that, during the climax of glaciation, the comparatively open space lying between Benbecula, South Uist, and Barra, on the one hand, and Skye, Rum, Coll, and Tiree on the other, must have been filled with glacier-ice. From Loch Bhracadail, Loch Eynort, Loch Bhreatal, and Loch Scavaig, thick masses descended and became confluent with the ice that ground out the deep rock-basin lying north of Rum. At the same time glaciers streaming out from the Kyles of Skye, Loch Hourn, and Loch Nevis united in Sleat Sound, and swept past Eigg in the same general direction, namely, towards south-west by west, until the *mer de glace* abutted upon the Outer Hebrides. Here, then, there would be intense grinding power exerted; and while the upper strata of the ice would overflow in a westerly or north-westerly direction such portions as were not too lofty, the lower strata of the glacier-mass would sweep south-west by south, until, as the ice rounded the opposing high ground, it found freedom to extend itself more to the west, and so to shelve off into deep water. Thus the trend of many of the submarine basins, as shown upon the map, indicates the direction followed by the undertow of the great *mer de glace*, and will not always be found to run parallel with the marks of glacial erosion upon the contiguous land. For example, the deflection-basins lying off the east coast of the Outer Hebrides trend from south-west to north-east, whereas the glacial markings on the land go across the islands from south-east to north-west. (See map, Plate IV.)

The two groups of basins which I have thus briefly described frequently become confluent, as one might naturally have expected. The upper reaches of Loch Carron, for example, occupy a fiord-basin, but where the hollow expands from the Kyles of Skye to north-west it forms a deflection-basin; it is along its lower margin, indeed, where this hollow attains its greatest depth. If the land were elevated for 600 ft. we should find the sea-bottom deeply scooped and hollowed in front of all the islets that stood right in the way of the ice-flow. But the map only shows such hollows as would form rock-basins and become fresh-water lakes. Yet if we examine the Admiralty charts, we shall observe that a

deep horse-shoe-shaped excavation would circle round the north end of Eigg, being evidently the work of the ice that came down Sleat Sound, and so with other islets; but when these are not very high, the erosion in front of them has been less excessive. In short, if the sea-floor were exposed to view, we should find that wherever abrupt ground rose opposite the mouth of a mountain-valley, a hollow of greater or less depth would curve round it like a collar. The island of Arran would afford a splendid example; the island of Mull, opposite Loch Linnhe, would be another hardly less striking; so would Rum, Eigg, Coll opposite the Sound of Mull, and many others. Thus the two groups of basins ever and anon coalesce, and in fact graduate into each other. Nevertheless, they must be distinguished, for while the fiord-basins invariably indicate the direct route taken by the *mer de glace*, the deflection-basins frequently indicate only the trend of the undertow, the upper strata having often overflowed the opposing land, and so swept on in the original direction.

But the most striking example of the union of *fiord-* and *deflection-basins* is afforded by the deep hollows that lie in the Sound of Jura, the North Channel, and the Irish Sea. Between Knapdale (Argyleshire) and the island of Jura, it will be observed that an elongated basin extends from Loch Craignish down the Sound of Jura, and is continuous with a great hollow that stretches south-east and south by the North Channel into the Irish Sea, and terminates at a point between Carnarvonshire and county Wicklow. In the first edition of this work I described the Jura basin as a fiord-basin, separated from the deflection-basin that lies north of Rathlin Island; but an examination of the latest issue of the Admiralty chart of the 'East Coast of Ireland' (No. 1824) shows that the two basins are confluent, and that the lip or edge of the great submarine hollow is marked by the 50-fathoms line. The deepest part of the Jura portion lies between Loch Crinan and a point nearly opposite the extreme south end of Jura Island. In this long narrow section the depths are very irregular; in fact, the hollow here consists of a string of small rock-basins, ranging from 83 to 110 fathoms in depth, the lip of the basin itself being 50 fathoms

from the surface; so that in actual depth, the upper reaches of the basin attain, at the most, 33 to 60 fathoms. From the south end of Jura the basin widens out, and as it does so it gradually shallows, attaining, however, an exceptional depth (70 fathoms) immediately opposite the north point of Gigha Island. Now these appearances are precisely such as might have been expected; the narrow and deep portions of the basin occur just in those places where the erosive power of the ice would be greatest; and, on the other hand, the basin shallows as the fiord-valley open outs, for the simple reason that there the ice had room to extend itself.

When, at a time of extreme glaciation, the confluent ice-masses were enabled to encroach still farther upon the bed of the sea, the Scottish *mer de glace* advancing upon the coasts of Antrim became confluent with the Irish ice-sheet. This is well shown by the manner in which the glacial markings in the extreme north of Ireland turn away towards the north-west and south-east, instead of pointing right out to sea. The Scottish ice-flow divided upon Ireland, passing westward into the Atlantic, and south-east by the North Channel into the Irish Sea, where it was continuous with the ice that overflowed the Isle of Man from north-west to south-east.

Since there can be no question that the Irish coast deflected the ice-current that streamed towards it from Scotland, there must have been great erosion upon the bed of the sea adjoining Ireland, and we ought to find there great hollows corresponding to the deep submarine troughs that occur along the inner margin of the Outer Hebrides, and in other similar positions. A glance at the map (Plate VIII.) will show that precisely the same appearances recur off the Irish coast. Opposite Rathlin Island we find a depth of not less than 133 fathoms; the dotted line upon the map enclosing all the area which is at, or over, 100 fathoms from the surface. It is evident that this deep part of the great submarine hollow does not rest in a fiord-valley like that which now forms the Sound of Jura; there is no sea-loch or deep land-valley opening out upon it from the Irish coast. If ground out by ice, that ice could not have flowed from Ireland. There can be little doubt, therefore, that we have here an

example of a *deflection-basin*; for it is just opposite Rathlin Island that the immense glacier-mass discharging by the Sound of Jura met with resistance to its progress. Rathlin Island, in fact, behaved like a large boulder in the bed of a stream; it stemmed the current, which was thus forced to flow east and west, and the usual result followed—a hollow was ground out in front. If the linear trend of the *fiord-basin* in the Sound of Jura indicates the former path of the glacier that formed it, not less does the crescent-shaped *deflection-basin* at Rathlin Island point out where the ice-current divided to flow in different directions.[1]

But, as I have said, the Jura basin and the hollow in front of Rathlin Island are only the deeper portions of one great submarine trough, the lip of which is formed by the 50-fathom line. Nearly midway between the Wigtownshire coast-line and the Irish coast, the Admiralty chart shows a long trench which runs parallel to the shores of the adjacent countries. This trench reaches the depth of 149 fathoms, and is deeper by about 70 fathoms than any part of the great submarine hollow between the deflection-basin of Rathlin Island and the termination of the great hollow itself in the Irish Sea. It is just where this deep excavation exists that the erosive power of the ice would be most vigorous, as my friend Mr. J. Horne has pointed out.[2] For the Scottish and Irish ice, uniting on the bed of the Irish

[1] The direction of ice-flow in Cantire and Islay, during the epoch of maximum glaciation, was from south-east to north-west. This at first sight seems to militate against the views expressed above as to an ice-flow from north to south in the intervening Sound of Jura. It must not be forgotten, however, that the Scottish area (land and adjacent sea-floor) has been subjected to the action of two separate 'general *mers de glace*.' The submarine basins round our coasts are thus the products of two epochs of glacial erosion. The second ice-sheet appears to have followed (with some remarkable exceptions, referred to in Appendix, Note C.) the same directions as its predecessor. I think it is probable that could we examine the sea-floor off the west coast of the mainland we should find evidence of similar differences in the trend of the two ice-sheets. There is good ground to believe that the second general *mer de glace* flowed nearly due south in the Sound of Jura and in Kilbrannan Sound just as it did in Nithsdale. I have seen what I take to be lateral moraines of that southern ice-flow in the south-west of Arran. The second *mer de glace* seems to have attained a thickness in the north and north-west nearly as great as that of its predecessor. But in the south and south-west its thickness appears to have been considerably less. I strongly suspect that many districts, which were completely overwhelmed during the earlier stage of general glaciation, appeared during the second stage as 'Nunatakkr,' some of them (such as Arran) sending down local glaciers to the great *mer de glace*.

[2] *Trans. Geol. Soc. Edin.* vol. ii. pt. iii. 1874.

Channel, must have been mutually subjected to intense compression and constriction; and such increased constriction means of course greater pressure, and, consequently, more effective erosion.

The great hollow, as we trace it south, gradually shallows to a depth from the surface of 52 fathoms at a point opposite Lambay Island, after which it again deepens to 84 fathoms, and finally shelves off at a depth of 50 fathoms. Taking the lip of the trough at 50 fathoms from the surface, we find that the extreme depths appear in the Sound of Jura (70 fathoms); opposite Rathlin Island (83 fathoms); in the Irish Channel, between Wigtownshire and the opposite coasts of Ireland (99 fathoms); and midway between Dublin Bay and Holyhead Bay (34 fathoms). Let the reader note the fact that the greatest excavation upon the sea-bottom opposite the west coast of the Northern Highlands is 528 ft. in the Sound of Raasay. This great depth is exceeded by the hollow in the Irish Channel, for if the whole area of the British Islands were elevated so as to convert the adjoining seas into dry land, we should find an elongated lake extending from the Scottish Highlands southwards to the region between Wales and Wicklow county in Ireland, a length of not less than 240 miles, with a maximum depth of 594 ft.

Besides the groups of basins now described, a number of small ones are indicated upon the map as scattered about at a distance both from the fiord-valleys and the islands. These are comparatively shallow, scarcely exceeding seven or eight fathoms in depth, and not often attaining even that. As a rule, their longer axis coincides in direction with what appears to have been the path of the *mer de glace*. Similar small hollows often occur in low-lying tracts on the land, as, for example, in the low grounds of Lewis, where they are seen to coincide in direction with the lines of glacial erosion. Some of these are rock-basins, and others are mere depressions in the glacial deposits.[1]

In fine, it seems to me that the distribution of submarine basins round the coast of Scotland strikingly confirms the

[1] I ought to mention that, owing to the small scale of the map, Plate VIII., it has not been possible to show many of the submarine hollows which are indicated by the Admiralty charts; only those have been noticed which could be adequately represented.

conclusions we had arrived at from an examination of the glaciated aspect of the land itself; namely, that the whole country—with the exception of the higher hill-tops—was at one time deeply smothered in ice, which flowed out from all the sea-lochs, overflowing the islands off the coasts, and only stopping at last in the deep waters of the Atlantic. And it is no less evident, to my mind at least, that the remarkable distribution of deep submarine hollows can only be accounted for by Ramsay's theory of the glacial origin of rock-basins.[1]

Reference has already been made to the wonderful abundance of lakes in Scotland. They are concentrated chiefly in the hillier parts of the country and in the rocky plateaus and uplands, but they occur at all levels, from a height of 3,500 ft. down to the coast-lands. At first sight it would seem almost impossible to classify them. And yet, as we have seen, they group themselves naturally into Lowland lakes, Mountain-valley lakes, and Corrie lakes. This classification, as I shall show, brings into view the fact that our lake-basins have been formed at different stages of the glacial period. No hard and fast line, however, can be drawn between the hollows occupied by fresh-water and the submarine basins round our coasts. Each and all owe their origin directly or indirectly to glacial erosion. But, while some are the work of the general *mers de glace*, others have been ground out by local glaciers. Hence it becomes possible to assign the formation of our rock-basins to successive stages in the glacial history of Scotland. I recognise at least four such stages—each of which was marked by the formation of a particular group of rock-basins.

1. *Submarine Rock-basins and certain Lowland Lakes.*—To this class belong all the depressions, whether upon the sea-bottom or the land-surface, which are due to the erosive action of the general *mers de glace*. It thus includes the great fiord-basins that occur in so many of the sounds, as in the Sound of Raasay, the Inner Sound, the Sound of Sleat,

[1] Some further remarks on glacial lakes will be found in Chapters XX., XXXII., and XXXIII. The student of glacial geology may profitably consult Penck's *Vergletscherung der deutschen Alpen*, iii. Abschnitt; and Böhm's 'Die alten Gletscher der Enns und Steyr,' Chaps. VII. and VIII. (*Jahrb. d. k. k. geol. Reichsanstalt*, 1885, Bd. xxxv.), for admirable discussions of the question of glacial erosion.

the Firth of Lorne, the Sound of Jura, Kilbrannan Sound, the Sound of Bute, the great depression in the North Channel, and the Irish Sea, &c. Most probably also to the same stage belong the deep basins in the *lower* reaches of some of our larger sea-lochs, such as Loch Long, Loch Fyne, Loch Kishorn, Loch Ewe, &c. Similarly, to this group must be assigned all the submarine deflection-basins and other depressions lying beyond the general coast-line of the mainland. Of our fresh-water lake-basins a considerable number also come into this group. Amongst these I may instance the numerous lakes scattered broadcast over the Outer Hebrides and the similar shallow depressions so abundantly developed upon the western seaboard of Sutherland up to a height of 600 ft. or thereabout. Some of these are true rock-basins, but a large proportion lie partly in solid rock and partly in glacial accumulations. Of the lakes of the Lowlands of Central and Southern Scotland nothing need be said. The only conspicuous sheet of water in that section of the country which may possibly occupy a rock-basin is Loch Leven. If it really be such it would come under the class of deflection-basins—a hollow eroded in front of an obstruction to the ice-flow.

2. *Rock-basins in Sea-lochs and Mountain-valleys.*—To this class of basins belong the great fresh-water lakes of the Highlands and Southern Uplands, and the deep depressions in most of our sea-lochs, as in Lochs Broom, Torridon, Carron, Nevis, Etive, and those in the upper reaches of Loch Fyne and Loch Long. It is probable, however, that not a few of these rock-basins, as well terrestrial as submarine, may have been partially eroded under the general *mers de glace*. Such, for example, may have been the case with the lochs that extend along the Great Glen. But as all those basins were occupied by ice at a later date, when, as will be shown in the sequel, the Scottish Highlands and Southern Uplands supported district ice-sheets and large valley-glaciers, the final modification of the basins must be assigned to that later stage of glaciation. The great majority of the basins of this second group, however, could not have come into existence under the general *mers de glace*, but have resulted from the grinding action of valley-

glaciers. Their geographical distribution and their relation to the high grounds which drain into them, taken in connection with the position of their terminal moraines and fluvio-glacial detritus, enable us to fix approximately the height of the snow-line at the time the hollows in question were eroded. In the mountain districts of Fannich Forest, Ben Wyvis, and Glen Cannich Forest, such lakes as Loch Fannich, Loch Vruin, Loch Glass, Loch Lungard, and Loch Mullardoch are the beds of glaciers that descended from snow-fields the lower limits of which are indicated approximately by the 1,500-ft. contour-line. The large lakes and valley-moraines of Lochaber imply a similar elevation for the old snow-line. In Sutherland, however, the position of the large lakes of Assynt and Reay Forest and their relation to the mountains show that in that region the snow-line reached a lower level, apparently not rising above 1,000 to 1,200 ft. In the West Highlands generally the snow-line stood at a lower level than in the central tracts—hardly exceeding 1,300 ft. The lake-basins and associated terminal moraines of the Southern Uplands indicate, on the other hand, an elevation for the snow-line of 1,500 to 1,600 ft.

3. *Rock-basins in the upper Reaches of Mountain-valleys and Cirque-lakes or Mountain-tarns.*—Towards the heads of those valleys in which the larger lake-basins of the preceding group occur, lakes of a similar character but smaller size are often encountered. At the lower ends of such lakes, or, as the case may be, a little farther down, terminal moraines are frequently conspicuous. Very often, however, such upper lakes are wanting. In some cases sheets of alluvium occupy their sites, showing that they have been silted up. In other cases they seem to have been drained by the deepening of their outlets, but in a still larger number of cases it is obvious that no lakes of the kind have ever existed. As an example of the class of lakes now referred to I may cite that of Glen Turret (Perthshire). In this glen two lakes are seen—the lower and larger one being evidently the bed of the old glacier which dropped the moraines that occur one mile below the end of the lake. This basin is an example of our second group. At the very head of the glen, a mile or so above Loch Turret, we find a

tarn occupying a marshy depression, at the lower end of which occur a series of remarkably fresh terminal moraines. Farther north, in the valley of the river Quaich, lies Loch Freuchie (1¾ mile in length), near the lower end of which we see conspicuous moraines. This basin is another example of our second group. No small lake occurs at the upper end of this valley, but well-marked terminal moraines appear about 4½ miles above Loch Freuchie; so that here, as in Glen Turret, terminal moraines occur at two distinct stages. The tarn at the upper end of Glen Turret is an example of our third group—in Glen Quaich no upper lake appears, but the terminal moraines show that a local glacier formerly occupied the upper reaches of that valley. In the case of the greater glens the two sets of valley-lakes and moraines are often much farther apart than is the case in Glen Turret. I have spoken of these two sets of lakes and moraines as occurring in many mountain-valleys, but, in general, only the larger and lower basins are present in our Highland glens. We may note, however, that in such cases many of the streams and torrents which flow into the large low-level lakes rise in cirques or corries far up the slopes of the encompassing mountains. Terminal moraines and glaciated rock-surfaces show clearly that each of these corries has been occupied by a glacier. Many of them contain lakes, while the rock-basin in other cases has been drained or filled up with detritus. The glacial appearances in such corries are usually extremely fresh—the moraines being not infrequently almost devoid of any vegetable covering. Most of the corries now referred to are met with below a height of 2,400 ft.—the majority occurring between that and 1,500 ft. They would appear to have been ground out at a time when the snow-line had risen to an average elevation of 2,400 to 2,500 ft. In the north-west Highlands, however, the snow-line at this stage descended to a lower level, and some of the glaciers, as we shall afterwards learn, succeeded in reaching the sea.

4. *Valley-lakes and Corrie-lakes at higher Levels.*—At still greater elevations we encounter yet another series of lakes. Excellent examples are seen amongst the Cairngorm Mountains and in the Lochnagar district. They occur up to a

height of 3,400 ft. or thereabout, and seldom descend below the level of 2,200 ft. Their distribution and position indicate for the old snow-line an average elevation of 3,500 ft.

Thus it happens that in mountain districts which do not exceed an elevation of 2,500 ft., only the lower-level corrie-lakes and moraines make their appearance; while in regions having an elevation of over 3,500 ft. we find representatives of both the lower- and the higher-level series. In cases where the orographical features of a district have greatly favoured the accumulation of snow above the level of 3,500 ft., considerable glaciers would appear to have descended much below the average elevation at which the true corrie-lakes occur. The Lochnagar district affords some interesting examples. In the upper reaches of Glen Muick we meet with two valley-lakes—the lower (Loch Muick) rather over two miles in length, occurring at an elevation of 1,300 ft. This lake is obviously the bed of an old glacier—its fluvio-glacial gravels being well developed in the valley below the lake. The comparatively large size attained by this glacier—it was not less than six miles in length—was due to the fact that it drained the major area of the Lochnagar snow-field. One and a half mile above Loch Muick we encounter another valley-lake (Dubh Loch) at a height of little more than 2,000 ft. Conspicuous moraines are associated with this lake, which is no less clearly the bed of a glacier that descended for 1,500 ft. below its snow-field—the snow-line being then at an elevation of 3,500 ft. On the northern slopes of Lochnagar only corrie-lakes occur—the beds of small glaciers that drained very limited snow-fields. They did not, therefore, descend so far below the snow-line—none reaching a lower level than 2,500 ft. Similar facts confront us in the Cairngorm Mountains. Towards the head of Glen Eunach, which is surrounded by steep precipices, we find Loch Eunach ($1\frac{1}{2}$ mile in length) at a height of 1,700 ft.—the lair of a glacier fed from a snow-field, the lower limits of which are indicated by the contour-line of 2,500 ft. High on the northern slopes of Braeriach, in a deep corrie (3,250 ft.), we see the spoor of a small glacier, which existed at a time when the

snow-line had risen to 3,500 ft. To the same epoch belongs the basin occupied by Loch Avon (2,400 ft.), with its well-marked lateral and terminal moraines. Here, again, it is obvious that the low level attained by the latest Avon glacier was due to the greater extent of its gathering-ground. We have only to contrast the drainage-area of Glen Avon with that of Glen Derry or Glen Beg to see why it is that in the latter only high-level corrie-lakes occur, while the former shows a long high-level valley-lake.

The same tale is told by every group of lake-basins in Scotland. Those which form our second series belong, as I have shown, to a stage when the snow-line in Central Scotland did not rise higher than 1,500 ft. above the present sea-level, while in the west and north-west it hardly exceeded 1,000 to 1,200 ft. in elevation. Along the northern and north-western seaboard, therefore, much of the low ground was mantled with more or less confluent ice-flows. This is shown by the abundant and wide-spread distribution of morainic débris. In the Central Highlands all the great valleys were filled with glaciers, but above these soared the mountain-ridges — no longer smothered under one far-extended *mer de glace*. Hence each glacier, as a rule, was isolated and confined to its own valley; the distance travelled, and the degree of erosion effected, being in direct proportion to the extent of the gathering-ground and the supply of snow. No corrie-basin dates its origin to this stage. The third group of rock-basins and moraines came into existence when the snow-line had risen to an average elevation of 2,400 or 2,500 ft. As in the case of the previous stage, however, it lay at a somewhat lower level along the western and northern seaboard. During the formation of this group the glaciers varied in size according to the extent of the snow-fields which fed them. Hence, from one and the same mountain mass one or more glaciers made their way down into the glens—reaching sometimes 1,000 or even 1,500 ft. below the snow-line—while others terminated far up the mountain-slopes in the cirque-like depressions from which so many of our mountain torrents now flow. And similar conditions obtained in the most elevated mountain-districts when the snow-line subsequently retreated to the 3,500 ft. level. In the

untains below that height glaciers ceased to exist—save in north-west, where, as during the preceding stages, the ›w-line lay at a somewhat lower level.

I have spoken of rock-basins having been formed at cessive stages, but it cannot have escaped the reader who consulted any good map of the country that lakes do not ur in every mountain-valley. Down all those valleys ciers certainly have flowed, as we see by the presence of ir old lateral and terminal moraines. How then does it ne to pass that lakes are not infrequently wanting? Now, many places it is obvious enough that such lakes have merly existed, their sites being indicated by sheets of ıvium. But in many other valleys we may be quite tain that no such lakes ever appeared. The explanation this apparent anomaly, however, is not far to seek. A k-basin can be eroded only under certain conditions. If ground incline at a relatively steep angle throughout the ıole course of a glacier, no rock-basin can be formed. The ıount of erosion may be great, but the configuration of ground — the continuously steep gradient — prevents aping-up of the ice, and consequently the erosive action the ice-flow cannot be concentrated upon any particular rtion of its bed. It is only when the relatively steep adient is interrupted by comparatively level or gently-clined reaches, that the conditions requisite for the cavation of typical valley-basins are obtained. Most of e larger rock-basins of this kind occur towards the lower ds of mountain-valleys, just where the steeper gradients re or less abruptly terminate. This, one may say, is the se with all the fiord-basins of the Highlands, and with a ge number of our more prominent fresh-water lakes. In these cases the form of the ground favoured the forma-n of rock-basins. The distribution of our upper-valley es and tarns tells precisely the same tale. When a cier was able to descend the steeper mountain-slopes and deploy on the relatively flat ground at the head of a glen, invariably ground out a basin there. But if it did not ach so far, but terminated on a more or less steep slope, e formation of a rock-basin became impossible.

CHAPTER XX.

DISTRICT ICE-SHEETS AND LOCAL GLACIERS OF SCOTLAND.

Date of formation of basins in valleys and fiords—Position and character of 'upper boulder-clay' in mountain-valleys—Boulder-clay ploughed out by valley-glaciers—Fresh character of later glaciation—District ice-sheets of Highlands and Uplands—Large valley-glaciers—Estimated height of snow-line—Coincidence of district ice-sheets, &c., with partial submergence—Evidence in Scandinavia for the occurrence of interglacial conditions prior to appearance of district ice-sheets and valley-glaciers.

IN an earlier chapter (Chapter XVII.) I ventured to express my belief that after the close of the second glacial epoch an interglacial stage succeeded, and was in its turn followed by a third relapse to glacial conditions. That an interglacial epoch supervened after the disappearance of the earliest *mer de glace* is demonstrated by the frequent occurrence of fresh-water and marine deposits intercalated between the lower and upper boulder-clays. The evidence in this case is too clear to be misunderstood. But the proofs of a second interglacial stage and of a third recrudescence of glacial conditions are not so readily recognisable. I cannot cite the occurrence of any section showing a succession of three boulder-clays, separated the one from the other by inter-glacial accumulations. Had evidence of this kind been obtainable, it is needless to say that the former existence of a third glacial epoch would have been recognised long ago. It is because the proofs are not so self-evident that they have hitherto failed to arrest attention. Nevertheless direct evidence, as I shall show presently, is not wanting.

Let us start in our investigation by recalling the origin of certain types of rock-basin which have been described in preceding pages. We have seen that there are some basins, typically represented by such lakes as Loch Lomond and

Loch Arkaig, which are confined to mountain-valleys and fiords, while certain others, of a different type, are well developed upon the sea-bottom along the inner margin of mountainous islands, as in the case of the submarine troughs off the coasts of Arran, Rum, and the Outer Hebrides. These last, as I have shown, are *deflection-basins*, excavated by the great *mers de glace* that streamed against those islands on their way to the Atlantic. The former, on the other hand, have been eroded by large valley-glaciers.

One can hardly doubt, however, that rock-hollows must have been ground out in many mountain-valleys at a time when the ice-sheets had reached their greatest development. Irregularities in the form of the ground would often impede the outflow of the ice, thus causing constriction and intensifying subglacial erosion. A sharp turn to right or left, or an abrupt change from a relatively steep gradient to a gently-inclined surface, such as frequently occurs in mountain-valleys, could not fail to increase the erosive action of an ice-sheet, with the result that rock-basins would gradually be hollowed out in such places. It does not seem probable, however, that a typical valley-basin, like that of Loch Lomond, could have been excavated entirely or even mainly while an ice-sheet covered the whole country. And the same may be said of many of the fresh-water lacustrine hollows and fiord-basins of Scotland. When a valley coincided in direction with the dominant trend of an ice-flow, it is obvious that the latter, meeting with no obstacles but having a free course, would be unable to erode any long and deep basin in the lower reaches of such a valley. On the contrary, its tendency would rather be to fill up with its subglacial detritus any depressions of the kind that might previously have existed. The typical valley-basin, now under consideration, has been ground out, not by a general ice-sheet, but by a local glacier.

At what stage of the Glacial Period, then, we may ask, were such basins formed? As each general ice-sheet was doubtless preceded and followed by the appearance of local glaciers, it is conceivable, as I have already pointed out, that the work of excavation may have commenced at the beginning of each glacial epoch, may have been interrupted

during its climax, and resumed before its close. But the grinding-out of rock-basins, attaining a length in some cases of fifteen miles, and minimum depths of 600 ft., must have taken a long time, even if we allow the rate of ice-movement to have been as great as that of existing glaciers in Greenland. We have no reason to suppose, however, that the valley-glaciers that heralded the advent of a general *mer de glace* and those that continued to flow after it had become inert and dead in the low grounds, were able to maintain their position in the lower reaches of our mountain-valleys sufficiently long to accomplish all that work of excavation. And even if we could suppose our valley-basins to have been ground out in the earlier stages of a glacial epoch, they yet could hardly escape being filled up with morainic materials by the *mer de glace* that followed. Thus we seem compelled to conclude that the basins in question have been eroded by local glaciers after the last general ice-sheet had disappeared. Now, were those local glaciers the immediate successors of that ice-sheet? This was formerly my belief, but I have since found reason for thinking otherwise. It seems to me in the highest degree probable that the glaciers which left the valley-basins as we now see them belong to quite a different stage of the Glacial Period.

From all that is known of the phenomena attendant on the decay of the last general ice-sheet, we cannot doubt that the retreat of the valley-glaciers into which that ice-sheet was resolved was marked by pauses. None of these, however, would appear to have been protracted. The glaciers lingered long enough here and there to give rise to great accumulations of kames and morainic débris, but we cannot show that any large rock-basins were excavated by them during such pauses. The kames often crowd the lower reaches of the great valleys, or are piled up on the low grounds opposite their mouths, showing that the glaciers maintained their position in such places for some considerable time. But no rock-basins have been scooped out in the valley-bottoms behind those morainic accumulations. If any excavations were effected they must have been very shallow, and thus were readily obliterated by the deposition of fluvio-glacial detritus when the glaciers recommenced

heir retreat. The whole aspect of the valleys, and the anner in which morainic and fluvio-glacial detritus are istributed, lead, in short, to the conclusion that the dis- olution of the last general *mer de glace* and of its succeeding cal glaciers was more or less continuous—and that any auses or temporary re-advances of the ice were of in- onsiderable importance.

In this connection it is particularly worthy of note that e boulder-clay, with which the lower reaches of our ountain-valleys are often well clothed, was not ploughed ut by the local glaciers that marked the dissolution of the st general *mer de glace*. This is perhaps best seen in the outhern Uplands, but the same appearances confront us gain and again in many Highland valleys, where the oulder-clay often paves the valley-bottoms up to the lower nds of the great lakes. The whole aspect of the till, indeed, ives one the impression that the only denudation it has xperienced in those regions since the time of its accumula- ion has been that of streams and rivers. In Chapter II. I ave referred to the terraced aspect of the boulder-clay in he valleys of the Southern Uplands, and similar terraces nay be observed again and again in the Highlands. Had he old glaciers of retreat occupied those valleys for a rolonged period of time, it is hardly possible that the oulder-clay could have been so strangely preserved. Its hief denudant has evidently been running water.

Let me now state another suggestive fact. When we dvance up a mountain-valley draining any considerable ract of elevated ground, we eventually come to morainic eaps of a normal type. Up to this point we may find boulder- lay more or less well developed, unless, indeed, it has been wept out by river-action or buried under fluviatile accu- mulations. Not infrequently the moraines repose upon a surface of till. Farther up the valley, along the shores of the lake, if such should happen to be present, only meagre patches of boulder-clay, or even none at all, may be en- countered. We climb the adjacent hill-slopes, and at first pass over bare rock or morainic débris, but by-and-by, if the acclivity be gentle, we again come on boulder-clay. These appearances may convince us that the boulder-clay originally

extended down the hill-slopes and covered the bottom of t valley. Nor can we hesitate to attribute its partial or ent disappearance to the erosive action of the glacier wh formerly occupied the lake-basin and deposited the morai and fluvio-glacial detritus at its lower end.[1]

Such phenomena are conspicuously displayed in t more elevated regions of the Southern Uplands, particula in South Ayrshire and Galloway, and led me long ago suspect that the local glaciers, into which the last gene ice-sheet was ultimately resolved, after retreating towa the heads of their valleys, had again advanced for a co siderable distance, and ploughed into and removed, or p tially removed, the boulder-clay. Subsequent observatio in the Highlands and the Inner and Outer Hebrides co firmed me in my suspicion, for in all those regions we m with appearances of precisely the same kind. My frie and colleagues, Messrs. Peach and Horne, had independen come to a similar conclusion; and the more recent work the Geological Survey in the North-west Highlands, as th inform me, shows clearly that after the dissolution of extensive ice-sheet, underneath which the upper boulder-c accumulated, a general advance of great valley-glaci succeeded. These later glaciers in many places coales upon the low grounds to form united *mers de glace* of c siderable extent, underneath which wide sheets of grou moraine or boulder-clay were formed.

It is particularly worthy of note that the *roc moutonnées* and striæ of the district ice-sheets and glac in question are usually well preserved, and altogether fres than those that resulted from the action of the general *n de glace*. Not only so, but the former always indicate

[1] The reader who is not conversant with glacial phenomena may be st here by what appears to be an inconsistency. If the boulder-clay be a gro moraine, why should it be laid down by one set of glaciers and swept awa another? The boulder-clay referred to, however, could only have been a mulated at a time when valleys and hills alike were smothered in ice. Ur neath a local or isolated valley-glacier ground-moraine is doubtless also for but it cannot accumulate to any extent, and is readily swept out by the ac of subglacial waters. Erosion, in short, is much in excess of accumula It is the well-preserved aspect of the boulder-clay in the lower reaches of mountain-valleys that leads us to believe that the local glaciers into which last general ice-sheet was resolved melted continuously and probably ra rapidly away.

ice-flow which coincided more or less closely with the actual slope of the ground, while the trend of the latter shows that the movement of the great ice-sheets was in accordance only with the average inclination of the surface. Hence the local glaciers often flowed in quite a different direction from that followed by the preceding *mer de glace*. Many excellent examples of this occur in the islands of the Inner and Outer Hebrides. The Long Island, as we have seen, has been overflowed by ice that moved out from the mainland across the Minch. (See Plate IV.) During that stage of general glaciation no local or valley-glaciers could possibly have existed. But after the ice-sheet had disappeared, many of the deep mountain-valleys were occupied by glaciers, some of which descended to the sea and calved their icebergs, while others piled up terminal moraines on the land. Thus, in Laxadale, near Tarbert, two sets of striæ occur—an older series traversing the district from south-east to north-west, and a younger series pointing down the valley from north-north-west to south-south-east. Similarly, from Ben More and Hecla, in South Uist, local glaciers have flowed into the Minch, nearly in the opposite direction to the trend of the old *mer de glace*. In each case, moreover, the later striæ and *roches moutonnées* are clearly differentiated from the older glaciation by their fresh and unweathered aspect. The same appearances present themselves on the Atlantic side of the islands. Thus Loch Suainabhal, in Lewis, is the bed of a considerable glacier, the well-marked terminal moraines of which occur close to the sea-coast at Traigh Uige. In this valley the general and the local glaciation are in the same direction, but the latter, as usual, is the fresher. Many similar examples might be cited from the mainland. In Applecross, for instance, Mr. Horne found that the general trend of the older glaciation is from south-east to north-west, while the local glaciation invariably follows the valleys which traverse the path of the old *mer de glace* at various angles. Between Kishorn and Applecross 'excellent examples of cross-hatching are visible, the older set pointing W. 30° N., and the latter, or valley-glacier markings, S. 28° W.'[1] In the mountain district of South

[1] 'The Intercrossing of Boulders in the Applecross Mountains' (*Trans. Geol. Soc. Edin.* 1894).

Ayrshire, which was mapped for the Geological Survey by Messrs. Peach and Horne and myself, similar phenomena are conspicuous. The contrast between the earlier *general* and the later *local* glaciation could not, indeed, be more striking. The former has affected the whole district up nearly to the highest elevations, the flat-topped mountains and hills being striated in certain general directions, and sprinkled over with erratics or sheeted more or less continuously with boulder-clay. In the adjacent valleys, on the other hand, the glaciation coincides with their trend, and is obviously the work of local glaciers, whose lateral and terminal moraines are constantly in evidence. These moraines sometimes rest upon boulder-clay—in other places the boulder-clay has been ploughed out from the bottoms and lower slopes of the valleys; but above the limits reached by the lateral moraines it reappears, often sweeping up the gentle acclivities and overspreading the tops of the adjacent hills.

There can be no question, therefore, that these later valley-glaciers and district ice-sheets—for the glaciers were not infrequently coalescent—form a distinct stage in the history of the Glacial Period. To describe their terminal moraines as 'moraines of retreat' of the last general *mer de glace* is certainly incorrect. They are clearly moraines of advance, formed during a subsequent recrudescence of glacial conditions. One can see that these glaciers attained a development in harmony with the physical conditions. The loftier the mountains, and the more extensive and capacious the gathering-grounds, the larger and more massive were the glaciers. It is notable also that as a rule the largest ice-flows were those that descended to the west coast, which is in accordance with present and most probably with past meteorological conditions. The greatest precipitation must always have taken place along our western sea-board. Few geologists seem to have realised the extent of the glaciation at the epoch in question. All the valleys of the Highlands were occupied by glaciers, which in some places, as in Caithness and Sutherland, coalesced to form district ice-sheets upon the lower grounds. Great ice-flows filled the fiords and sea-lochs of the Northern and Western

ghlands, at the mouths of which they calved their icebergs. nilarly, in the Outer and Inner Hebrides, numerous in- pendent snowfields existed, from which glaciers descended d not infrequently reached the sea. The same was the se with some of the large valley-glaciers of Arran. On eastern slope of the mainland great ice-streams in like nner flowed down the valleys into the regions of the es, at the lower ends of which, or a little farther down, encounter their terminal moraines and fluvio-glacial vels, &c. Loch Earn, for example, is the deserted bed of arge glacier which flowed as far east as Ochtertyre, where encounter its gravelly moraines. The same neighbour- od affords a number of similar cases. Thus, as we have eady seen, a glacier has formerly occupied the basin of ch Turret and flowed for a mile or so farther down the ley. So, again, the valley of the Quaich, a tributary of the er Bran that enters the Tay a little above Dunkeld, rds an excellent illustration of the same phenomena. vancing up Strath Bran we find the bottom of the valley thed with boulder-clay, which, save for fluviatile denuda- n, remains much as it was when the old *mer de glace* lted away. No trace of terminal moraines is met with til we have passed Amulree, when a fine series suddenly s in an appearance. These have obviously been dropped the glacier that occupied the valley of the Quaich and basin of Loch Freuchie. Terminal moraines of like age ur in several of the small glens of the same neighbour- od. The position occupied by these moraines shows that snow-line at the time of their accumulation must have od at the level of 1,400 to 1,500 ft. above the sea. In rt, the conditions that obtained at this stage are those t gave rise to the rock-basins and terminal moraines de- ibed in the preceding chapter as constituting our 'second up.' Throughout Scotland it was distinctly an epoch of al or valley-glaciers, and in certain regions of district ice- ets.

Let it be understood, therefore, that after leaving the lands and entering the mountain-valleys, the only glacial umulation met with is boulder-clay until the lake-region pproached, when all at once terminal moraines put in an

appearance. Up to this point boulder-clay is usually more or less conspicuous, clothing the lower slopes of the adjacent hills, but above the moraines it suddenly disappears, either wholly or in large measure, from the valley-bottom and the lower hill-slopes. It often reappears, however, at higher levels, and even on the hill-tops between contiguous valleys it not infrequently extends in sheets.

We may now advance a step farther. I have shown that the scooping out of the boulder-clay in our mountain-valleys and the formation of rock-basins could not have been the work of the decadent glaciers into which the last general *mer de glace* was resolved. That ice-sheet disappeared from the mountain-valleys below the lake-regions, leaving behind it a more or less thick covering of ground-moraine or boulder-clay. We cannot suppose it likely that, after sparing its bottom-moraine in the lower reaches of the mountain-valleys, it should proceed to erode the boulder-clay from the valley-bottoms farther up the glens. The sweeping out of that accumulation was the work of advancing, not of retreating glaciers. In a word, the epoch of district ice-sheets and valley-glaciers is to be clearly distinguished from the preceding epoch of general glaciation. More than this, the two epochs would appear to have been separated by a prolonged interval of milder conditions. In evidence of this I cannot cite the occurrence of interglacial deposits. No deposits of the kind, so far as I know, separate the 'upper boulder-clay' from the morainic heaps and boulder-clays of the local or district glaciation. It is possible that such may exist and may yet be recognised, for their existence has not hitherto been suspected. Nevertheless, as will be shown in the succeeding chapter, the great valley-glaciers and district ice-sheets were contemporaneous with a movement of depression—the marine accumulations formed during that submergence having been ploughed into by the glaciers in question. In short, it can be proved that after the formation of the 'upper boulder-clay,' Scotland sank for more than 100 ft. in the sea, after which another recrudescence of ice-action took place. The occurrence of terrestrial and fresh-water interglacial deposits underneath the valley-moraines would doubtless form a valuable link in the chain of evidence.

even without such evidence many facts are forth-
ing to show that an interglacial epoch of long duration supervene after the disappearance of the last general sheet and before the advent of the extensive glaciers of ch I have been speaking.

To carry the reader with me it will be necessary to icipate certain evidence that falls to be given in greater ail in subsequent chapters. Meanwhile, let it be remem-ed that during the formation of our upper boulder-clay Scottish and Scandinavian *mers de glace* coalesced on floor of the North Sea. The glacial phenomena along the ole eastern sea-board of Scotland leave us in no doubt such was the case, and, as we shall learn in the sequel, ilar evidence is forthcoming from the eastern districts of gland. A glance at the map (Plate IX.) will show that Scandinavian ice-sheet, during its greatest extension—en it was confluent with the British *mer de glace*—ed far south in Central Europe, reaching even into ony.

To this epoch of maximum glaciation succeeded a pro-ged interval of milder conditions, at the culmination of ich the climate of Europe was certainly not less tem-ate than it is in our own day. Eventually that genial erglacial epoch passed away, and glacial conditions again ervened. Once more from Scandinavia streamed forth reat *mer de glace*, which, however, was inferior in extent the earlier ice-flow. (See Plate X.) This lesser *mer de* *e* flowed south to beyond Berlin and the valley of the e, and was confluent in the basin of the North Sea with ice that streamed out from Britain. Underneath this sheet the upper boulder-clays of the Elbe Valley and the grounds of Britain were accumulated. Again glacial ditions disappeared and a milder climate ensued, as is ved by the occurrence of numerous interglacial deposits he Baltic coast-lands. These last, as we shall learn sub-iently, rest upon boulder-clay and are overlaid by the ind-moraine of another and younger *mer de glace*. A ice at the map (Plate XI.) will show that this later ice-et was by no means so extensive as its predecessor. The in of the Baltic was indeed occupied by one gigantic

glacier which encroached upon the Prussian provinces and invaded southern Sweden and eastern Denmark. At the same time great glaciers occupied all the fiords of Norway, at or near the mouths of which they calved their icebergs. But the North Sea was not again invaded by any Scandinavian ice-flow.

Now it is obvious that the ground-moraines of this well-marked glacial epoch in Scandinavia and the Baltic region cannot be on the same geological horizon as the upper boulder-clay of the low grounds of Britain. The latter was accumulated at a time when the British ice was confluent with that of the Continent. The youngest boulder-clay of the Baltic region, on the other hand, is the product of a much more restricted ice-flow. With what stage in the British series, then, was the great Baltic glacier contemporaneous? We can hardly doubt that our district ice-sheets and local glaciers were its equivalents in time. And as the advent of the great Baltic glacier was preceded by a well-defined and long-continued interglacial epoch, it is obvious that similar climatic changes must have been experienced in our islands. After the dissolution of the last general ice-sheet in Scotland —that, namely, underneath which our so-called 'upper boulder-clay' was accumulated—a long interglacial epoch must have supervened. When at last these milder conditions had passed away, an arctic climate again prevailed—district ice-sheets and large local glaciers coming into existence in our mountain regions, and in many places descending to the sea, where their icebergs were shed.

We may anticipate, therefore, that fresh-water and terrestrial accumulations belonging to that particular interglacial stage will yet be detected in Britain. These we shall hardly meet with in our great mountain-valleys, where the conditions for their preservation hardly obtained; but they may well occur among the older alluvia of the Lowlands. It is probable, indeed, that such deposits are already known, and that we have hitherto failed to recognise their true position in the series. Certain beds which have been included among our early postglacial deposits will eventually prove, I believe, to belong to this particular interglacial epoch.

Having now given reasons for my belief that an inter-glacial epoch supervened before the appearance of the latest extensive development of snow-fields and glaciers in the mountainous regions of Scotland, it will be necessary to consider certain additional evidence which will help us to complete our history of that stage of the Glacial Period.

CHAPTER XXI.

ARCTIC SHELL-BEDS OF SCOTLAND.

Shelly clays of maritime districts—Position of these deposits with respect to older glacial and fluvio-glacial accumulations—The 100-ft. terrace of the Forth, Clyde, and Tay—Organic remains—Ice-floated stones and boulders—Crumpled and contorted beds—Relation of terrace to the morainic débris, &c., of district ice-sheets and local glaciers—Physical conditions of the country at the epoch in question—Glacial lakes; the Parallel Roads of Glenroy.

THE deposits now about to be considered are memorable in the annals of geological discovery. Mr. Smith, of Jordanhill, was the first to introduce them to notice, and the phenomena as described by him at once convinced the most sceptical that an arctic climate had really at one time characterised our country. The deposits referred to occur more or less abundantly at many points along the sea-board, especially where the shore shelves sufficiently to give rise to a flat beach. They appear, for example, in the low flats that fringe the margins of the Forth and the Clyde, where they are more or less concealed below a thick covering of re-arranged or recent accumulations. The low ground upon which Glasgow is built, and which, as we trace it westward, widens out on either side of the river Clyde, especially south by Paisley, Johnston, and Houston, so as to form a broad expanse many square miles in extent, is composed, for the most part, of fine sand, silt, and brick-clay, the lower portions of which deposits all belong to the glacial series. Of like nature are the under portions of those wide terraces of sand, silt, and clay, through which the river Forth flows for several miles before joining its estuary. Along the borders of that estuary similar deposits continue, and are occasionally exposed when the upper or more recent accumulations are thin or wanting, as at Kirkcaldy, Elie, and Portobello. The same

appearance recurs upon the coasts of the Firth of Clyde and many of the sea-lochs in that region. Brick-clays occupying a like position are found in several localities south from the Clyde, as at Stevenston, Monkton, Girvan, Ballantrae, and Stranraer. North of the Clyde they have been detected here and there in some of the fiords. On the east and north-east coasts they have not been so frequently observed, but deposits of this age appear at Glencarse, Errol, Barry, and Montrose, and like accumulations have been noted in the maritime districts of Aberdeenshire and the borders of the Moray Firth. It is highly probable, indeed, that if the recent shingle, sand, and silt were removed from the flat beaches that skirt a large part of the coast-line, the deposits now about to be considered would be found more frequently. There can be little doubt, at all events, that in some places they cover the bed of the sea; for the shells they contain, and to which I shall presently refer, have occasionally been brought up in dredges.

None of these deposits has ever been detected at high levels or in the interior of the country. It is true that beds of brick-clay, loam, and silt are of common occurrence there; but these beds, however much they may sometimes resemble those I now refer to, yet cannot be confounded with them. The superficial brick-clays in the interior of the country are, for the most part, unfossiliferous; but when they do contain fossils, these invariably prove to be the remains of terrestrial and fresh-water organisms. Now the brick-clays of maritime and low-lying districts more frequently contain fossils, and these are all, with hardly an exception, estuarine and marine.

The highest level at which the deposits now under review have been obtained is 125 to 135 ft., or thereabout, above the sea. Where they have suffered least denudation they occur in the form of a well-defined terrace, the upper surface of which is 100 ft. or thereabout in height. This is well seen in the basins of the Forth, the Clyde, and the Tay. Again, in some places the deposits are met with upon more exposed coast-lines, where they form what are known as raised beaches. Most frequently, however, they have experienced much denudation, and have apparently disappeared from many maritime districts where they cannot

Fig. [illegible]. The C[illegible]

have been well developed at one time. But in such ons we often encounter them in patches or more con-able stretches, peering out from underneath younger mulations. In short, as I have already remarked, there probably few places round our coasts where the deposits lestion do not occur, either at the surface or concealed w beds of more recent origin.

n the basin of the Forth there is an excellent develop-t of the 100-ft. terrace. It is well seen on both sides of estuary, but is best developed along its upper reaches, icularly between Falkirk and Stirling. In that district pears as a flat terrace, overlooking the low plain known le 'Carse.' In the neighbourhood of Falkirk its upper

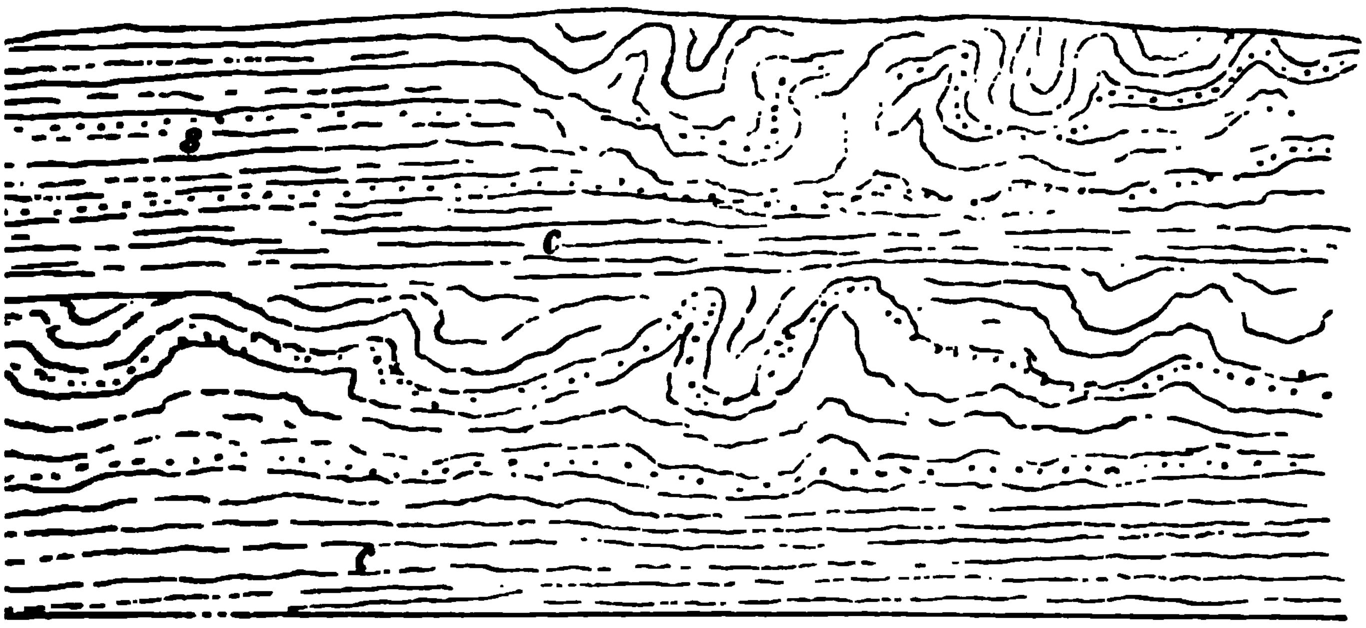

Fig. 56.—Contorted beds; clay *c*, and sand *s*: Portobello.

; is indicated by the 100-ft. contour-line on the Ordnance ey map, but as the terrace is followed up the valley rds Bonnybridge and Stirling, it rises to a height of ft. or thereabout above the level of the sea. The sits of which it is composed consist chiefly of tough, y laminated, plastic brick-clays, which usually form the of the series, and are overlaid by alternations of fine and sandy clay. Along the inland margin of the ce the highest beds often consist of fine gravel. tered through the brick-clays striated stones occasionally r. Here and there also the beds are much crumpled confused, great sheets of clay 'being rolled over and , and involving the associated sands for considerable zontal distances.' [1] Similar appearances have been from

[1] *Memoirs of Geol. Survey of Scotland*: Explanation of Sheet 31.

time to time exposed in the clay-pits at Portobello, and at Tyrie in Fifeshire.

I have in a previous chapter described the crumpling and contortion of the beds in the till. It will be remembered that the character of these contortions and crumplings plainly pointed to the exertion of force in one determinate

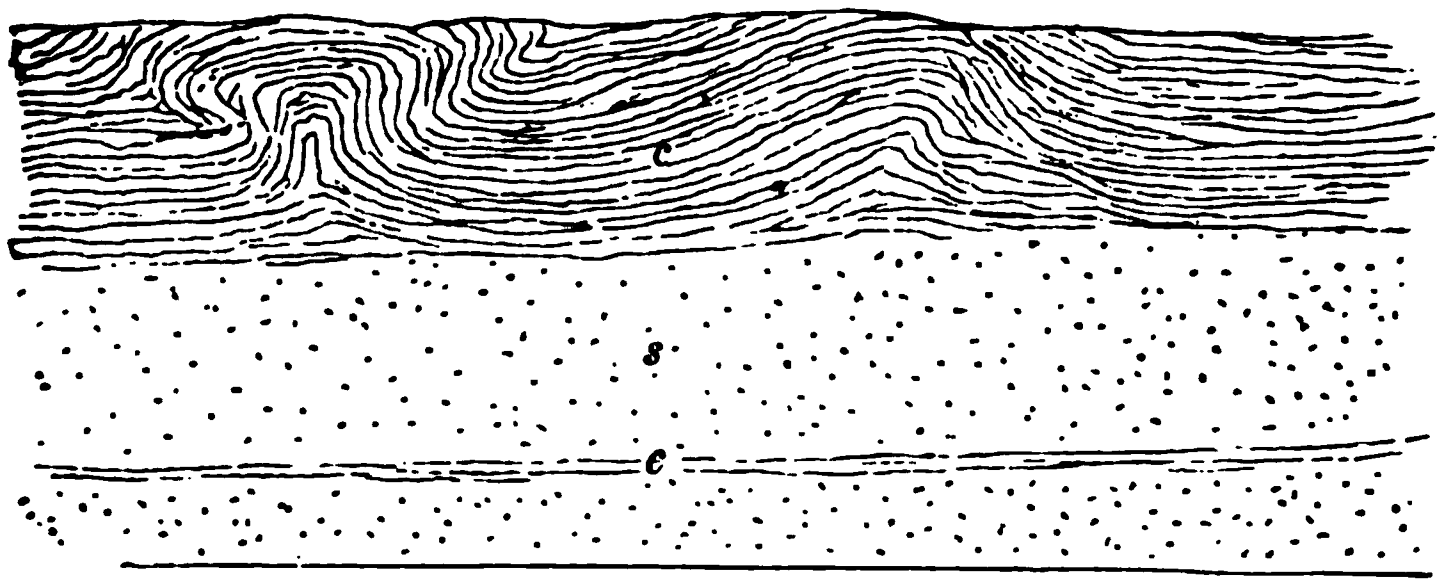

Fig. 57.—Contorted beds; clay *c*, and sand *s*: Leith. (Depth of cutting 6 ft., J. Croll.)

direction. The beds, in short, were shown to be curved over in the direction followed by the till and the rock-striations, indicating the strong pressure of glacier-ice. But the case is widely different with the contortions visible in the deposits of the 100-ft. terrace. These are exceedingly irregular, and are just of such a character as we should expect would result from the grounding of ice-rafts. The

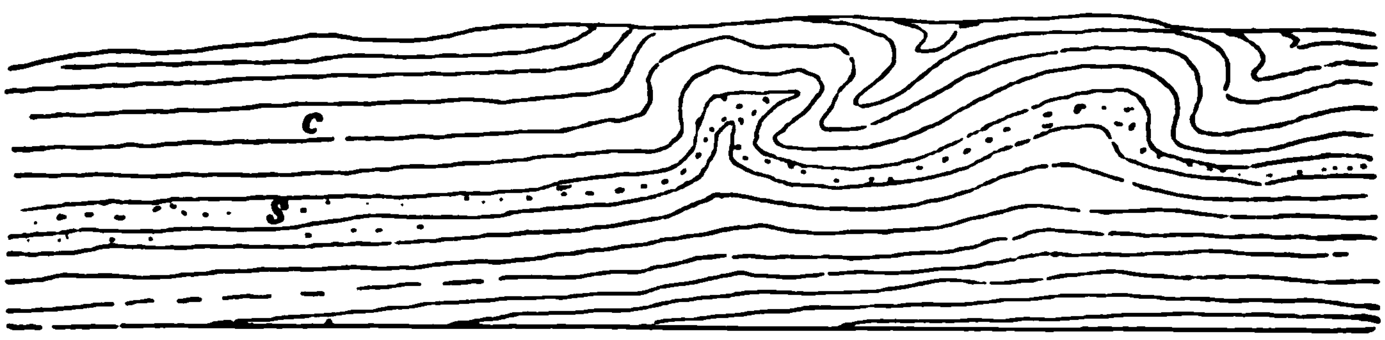

Fig. 58.—Contorted beds; clay *c*, and sand *s*: Portobello.

rough sketches (Figs. 56–59) give a general idea of the appearances presented. One can hardly doubt that the submarine banks of sand and mud off the North American coast must present very similar appearances after they have been bumped and crushed, and pushed forward by pack-ice as it runs aground.

The beds of the 100-ft. terrace seldom contain organic remains, such as have been met with being of an arctic type. Bones of the small arctic seal were obtained from the beds at Tyrie,[1] Portobello,[2] Camelon, and Grangemouth.[3] That these deposits are of later date than the last general

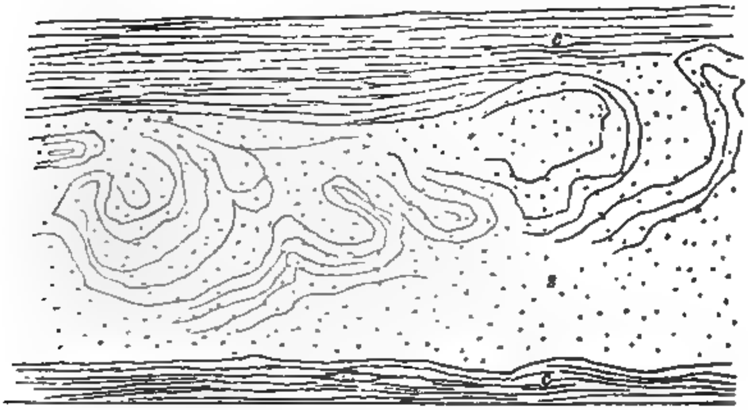

Fig. 59.—Contorted beds; clay *c*, and sand *s*: Portobello. (Depth of cutting 6 ft., J. Croll.)

mer de glace is proved by the fact that they rest in most places upon the upper boulder-clay, while here and there they lap round the kames and åsar that overlie that clay. They are therefore subsequent in date to the retreat of the last general *mer de glace*. The accompanying section shows

Fig. 60.—Diagrammatic view of drift deposits of the basin of the Forth. *b*, recent beach deposits; *c*, brick-clay, &c., *k*, kames series; *t*, till or boulder-clay.

their relation to the underlying glacial and overlying post-glacial beds. (Fig. 60.)

In the valley of the Clyde, at the same height above the sea, a similar terrace is well developed, and is shown upon the

[1] Allman (*Edin. New Phil. Journ.* 1858, vol. viii. p. 147).
[2] *Ibid. loc. cit.* 1859, vol. x.
[3] Turner (*Proc. Roy. Soc. Edin.* 1869–70, pp. 105–114).

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Geological Survey map of that region. Like the terrace of the Forth valley, it is composed of laminated clay, sand, and gravel, shows a level surface, and rests upon an eroded base of boulder-clay. I have referred to the occurrence of occasional stones and boulders in the deposits of the Forth terrace. They are likewise met with here and there in the beds of the corresponding terrace in the Clyde valley. Some of these may possibly have been carried by seaweeds, but the more probable agent of transport was floating ice, the presence of which is independently vouched for by the contorted and crumpled strata. We can often satisfy ourselves that the erratics have been dropped into their present positions by examining the surrounding laminæ. Fig. 61 represents an isolated boulder of sandstone about 2 ft. in diameter, which occurs in a deposit of finely laminated clay. It will be

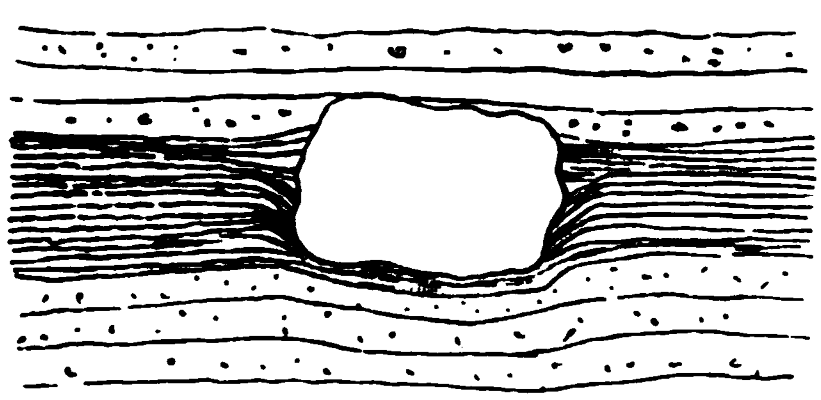

Fig. 61.—Boulder in stratified deposits, near Uddingston, Lanarkshire.

observed that the laminæ below the stone are bent down as if by pressure from above—showing that the stone fell with some force upon what was then the bottom of the sea or estuary. The upper part of the boulder which projected above the level of the bottom was then gradually buried by the increasing sediment, as one may see by the mode in which the laminæ curve up, and at last sweep over the wanderer. We can hardly doubt that the carrying agent in this case was floating ice.

In the basin of the Tay the 100-ft. terrace is again conspicuous.[1] It may be followed up the valley from Dundee as far as Luncarty above Perth, and it is likewise well developed in the lower reaches of the valley of the Earn, a tributary of the Tay. At and below Perth it is composed chiefly of laminated brick-clay and fine sand, which here and

[1] *Prehistoric Europe* p. 386.

ıere contain erratics, large and small. The beds also are ;casionally crumpled and contorted. Above Perth the de-)sits become coarser—sand, gravel, and shingle predomi- ıting as the beds rise along the slopes of the valley and .erge into broad flats and terraces of fluviatile origin. At ıe mouths of the small upland valleys that open from the chils upon Strathearn large cones or fans of coarse de- itus are piled up at the edge of the 100-ft. terrace, with hich they are obviously contemporaneous. Much rock- .bbish also and large erratics occur embedded in the terrace ıelf, particularly along its margin. The deposits agree ith those of the terraces of the Clyde above Glasgow and the upper reaches of the Forth in being singularly devoid organic remains. At Errol, however, shells of an ex- emely arctic type, such as *Pecten groenlandicus*, *Leda ·ctica*, *Tellina myopsis*, &c., occur in the clay.[1]

It is specially worthy of note that the 100-ft. terrace ısses beyond the estuary of the Tay, and in a more or less ·nuded state continues along the coast as far as Arbroath. t Barry[2] and Arbroath[3] it has yielded relics of a marine ctic fauna. At many other places on the coasts of Scot- nd raised beaches occur at approximately the same height; ıt the deposits are often much denuded, and when this is .e case they lose their terrace-like appearance. When they :e composed largely of coarse gravel and detritus, however, ıey are generally well preserved. Few of these old raised eaches have yielded any fossils; they consist generally of oarse shingle mixed with sand and gravel, and not infre- uently are charged with angular erratics, large and small. ome of these last may have been derived from pre-existing oulder-clay, others have in all probability been dropped om floating ice. On the east coast of Sutherland, at rora, fluvio-glacial gravels rest upon the surface of a ised beach belonging to this series, and at Montrose, as r. Howden has shown, they are covered by morainic gravel ıd shingle. When the beaches are best preserved they go ı to heights of 120 to 135 ft. or more above present high-

[1] Jamieson (*Quart. Journ. Geol. Soc.* 1865, p. 196).
[2] Robertson and Crosskey (*Mon. Post. Tert. Ostracoda*, p. 75).
[3] J. C. Howden (*Trans. Geol. Soc. Edin.* vol. i. p. 141).

water. Those which are composed largely of fine-grained materials seldom can be traced quite so high, but seem to range in elevation from 75 ft. or thereabout up to 100 ft. or so. The beaches are most clearly developed where the coast is low and the land shelves more or less gently seaward. Hence they are best seen along the eastern sea-board, and on the borders of the Moray Firth. At various points on the coasts of Galloway and Ayrshire, however, they occur in tolerable preservation. They seldom occur in the Highland sea-lochs, but now and again they may be encountered in the lower reaches of such fiords, as in Loch Carron, where they have been studied by my friends Messrs. B. N. Peach and J. Horne. With regard to that region Mr. Horne writes me as follows:—'At the mouth of Loch Carron the 100-ft. beach is remarkably conspicuous, forming broad flat terraces on both sides of the loch. From the point where the loch narrows, west of Strome Ferry, it can be followed to Fernaig and onwards to Plockton, while on the north side it may be traced from North Strome by Ardaniaskin to Reraig. Loch Carron runs inland for a distance of six miles east of Strome Ferry, but in this section of the loch no vestige of the 100-ft. terrace appears either on the sides of the fiord or at its head. Later beaches occurring at elevations of 50 ft. and 25 ft. respectively are prominently developed at the head of the loch and at North Strome—the 25-ft. beach being also readily traced along the base of the 100-ft. terrace west of Strome Ferry.' (These later beaches fall to be described in the sequel.)

'The abrupt termination of the 100-ft. beach at North Strome is a striking fact, and seems to point to the conclusion that during the 100-ft. depression Loch Carron was occupied by a large glacier—the terminal front of which remained more or less stationary at Strome Ferry for a considerable time.

'This suggestion is confirmed by the evidence supplied by similar phenomena in Loch Kishorn. In that district the 100-ft. beach is met with at the village of Kishorn and at Auchintraid. Not a trace of the beach in question, however, appears on the north side of this sea-loch, where the valley-glaciers coming from the lofty mountains of

Applecross have left abundant morainic débris below that level.

'Along the western sea-board of the peninsula of Applecross the 100-ft. beach can be traced northwards from the village of Applecross, either as a gravel-terrace or as a ledge carved out of the solid rocks, as far as Chuaig. There it disappears, and it is highly probable that in this case also its abrupt termination may be due to the existence in Loch Torridon of a great valley-glacier during the 100-ft. depression.'

Although such terraces are of infrequent occurrence in the sea-lochs (save in the lower reaches thereof), they occur now and again on the open coasts, as in Applecross, just mentioned, and on the west coast of Jura, where they range in height from 105 to 130 ft.

It is in the lower basin of the Clyde where deposits belonging to the epoch of the 100-ft. terrace have yielded the most abundant traces of marine life. In this region the upper portions of the deposits have been denuded, so that the beds seldom occur at greater heights than 40 to 50 ft. above the sea. They are thus usually covered unconformably by accumulations of postglacial and recent age. The following section, taken at the brick-works of Kilchattan in Bute, shows the general character of the beds at these two levels—[1]

1. Vegetable soil.
2. Sand and gravel, well stratified, false-bedded, passing down into a sandy clay with gravel, 10 or 12 ft.
3. Red clay without stones or shells, becoming dull olive green in lower part, 1 to 2 ft.
4. Bed of fine dark clay, full of *Tellina proxima*, &c., many of the shells retaining both valves, 2 ft.
5. Finely laminated brown and reddish brick-clay without stones or shells, 15 to 18 ft.[2]
6. Hard tough red boulder-clay; its upper surface hummocky and irregular.

Irregularly scattered throughout the marine deposits under review a few angular, sub-angular, and smoothed stones and boulders are now and again met with—here and

[1] A. Geikie, 'The Glacial Drift of Scotland' (*Trans. Geol. Soc. Glas.* vol. i. p. 132). See also papers by Messrs. Robertson and Crosskey in *Trans. Geol. Soc. Glas.* and *Palæontographical Society*, vol. xxviii.

[2] This clay very commonly occurs between the underlying till and overlying shelly clays. It is generally unfossiliferous, but occasionally yields entomostraca and foraminifera.

there crowding thickly together. A few of the stones show glacial markings, but the majority are either rough and angular or rounded and water-worn. Occasionally the beds are confused and contorted, but frequently no trace of disturbance is visible. A large percentage of the fossils are northern and arctic forms. And since these occupy their natural position—having lived and died and become entombed just where we now find them, we cannot doubt that the sea in which the brick-clays and associated deposits were accumulated was considerably colder than the water that now washes our shores. The character of the climate is still further indicated by the northern and arctic mosses which in some places occur in considerable abundance. In short, it is obvious that during the accumulation of the marine beds which immediately overlie the upper boulder-clay, the climate of Scotland must have approximated in severity to that of Greenland.

It remains now to show what relation these fossiliferous marine deposits bear to the morainic débris of the local ice-sheets and valley-glaciers of the third glacial epoch described in the preceding chapter. In the first place let it be borne in mind that the marine deposits in question are clearly of later date than the upper boulder-clay and the åsar and other fluvio-glacial detritus, which accumulated during the melting of the last general *mer de glace*. In the preceding chapter I have tried to show that after the disappearance of that *mer de glace* interglacial conditions supervened; and brief reference was made to the glacial phenomena of North Germany, Scandinavia, &c., to prove that those interglacial conditions continued for a long time. If, as I believe probable, a considerable portion of our so-called postglacial alluvia belong to this stage, we may by-and-by learn something definite as to the character of the plants and animals which lived in Scotland contemporaneously with those which have left their remains in the interglacial deposits underlying the upper diluvium of the Baltic coast-lands. Probably Britain at this time was continental, and eventually became clothed with a temperate flora like that of the present, and inhabited by Megaceros, red-deer, wolf, horse, and other mammalia. However that may have been, it is

certain that towards the close of that interglacial epoch the climate became cold, and the land was eventually submerged to the extent of 130 ft. or thereabout. At the same time great snowfields accumulated in our mountainous districts, and large glaciers descended the valleys, often for long distances, into the lowlands, more especially in the north, where they often coalesced to form more or less continuous *mers de glace*. All the great sea-lochs of the north and west were occupied by glaciers which shed their icebergs in the sea, while on the eastern slope of the watershed glaciers flowed down as far at least as the lower ends of the large freshwater lakes. Similarly in the Southern Uplands large district ice-sheets and valley-glaciers existed. It was owing to the presence of glaciers in the Highland sea-lochs that the sea was unable to form conspicuous beach deposits there. The sudden termination of the 100-ft. terrace above Strome Ferry indicates that Loch Carron was occupied by a large glacier, at the time the terrace was accumulating. On the east coast the glaciers did not as a rule reach the sea, although in Forfarshire they came down to within a short distance of it, so that their morainic gravels were accumulated upon the marine deposits forming there. The evidence, indeed, leads to the belief that the movement of depression preceded the extension of the glaciers to the sea-coast. Thus, before a glacier came to occupy the mountain-valley of Loch Lomond, that valley appears to have existed for some time as a fiord, in which a somewhat boreal marine fauna flourished. The evidence of these changes may be shortly stated. During the construction of the Forth and Clyde Railway a section was exposed near Drymen Station which showed a mass of tough boulder-clay overlying some seven feet of a laminated blue clay, from which were obtained a few sea-shells and, near the base of the deposit, the antler of a young or a female reindeer.[1] Mr. Jack (now Government Geologist of Queensland), who geologically surveyed the district where this section occurs, has shown that the overlying boulder-clay is the same as a remarkable shelly boulder-clay which he traced over a considerable area

[1] *Proc. Roy. Soc. Edin.* vol. i. pp. 163, 247 ; *Trans. Geol. Soc. Glas.* vol. i. p. 70.

in the lower valley of the Endrick, which enters Loch Lomond at its eastern angle. This boulder-clay does not rise to a greater height than 320 ft. above the sea. Mr. Jack describes it 'as a true typical till in every respect analogous to the old boulder-clay or till of the Lowlands of Scotland.'[1] The clay is tough, unstratified, full of glaciated stones, and brown in colour like the subjacent red sandstone. But its most noteworthy peculiarity is the presence of worn and broken fragments of marine shells, which are scattered irregularly through the clay just in the same way as the stones and boulders. He believes this shelly till to be of more recent date than the old till which was formed under the general *mer de glace*. The shells in the Endrick till, according to him, have been derived from a pre-existing interglacial deposit, of which the laminated shelly clay that contained the reindeer's antler is a fragment. According to Mr. Jack the succession of changes was as follows:—*first*, a period of excessive glaciation, when the whole country was smothered in ice; *second*, a time when the great ice-sheet melted away and Loch Lomond formed an arm of the sea, which was tenanted by shells that indicate a colder temperature than that which now prevails round our shores; at that time the sea must have risen at least 108 ft. above its present level, and the reindeer may then have browsed on its shores; *third*, a period when ice once more filled up the great mountain-valley in which Loch Lomond lies, and 'mounted the rising ground between the Lower Endrick and the Leven to a height of at least 320 ft.' This latest great advance of the glacier resulted in the wholesale demolition of the marine deposits which had gathered in the Loch Lomond fiord. The ice ground up the loose clays, sands, and gravels along with the shells and other marine organisms that lay upon the sea-floor and incorporated these with its bottom-moraine. Thus it is that broken and rolled shell-fragments, and occasional water-worn stones, are found scattered confusedly through the matrix of the tumultuous unstratified till.

The shelly till is overlaid in part by a considerable thickness of bedded mud, clay, sand, and gravel, amongst which

[1] *Trans. Geol. Soc. Glas.* vol. v. p. 5.

now and again occur layers of tough clay with stones, some of which are water-worn, the bulk of them, however, being blunted and subangular, and a few striated. Here and there these stratified deposits have yielded water-worn marine shells, and hence they were formerly believed to indicate a submergence to the extent of 260 ft. or thereabout. The shells, however, are all *remaniés*, and have doubtless been derived by fluvio-glacial action from the bottom moraine of the old glacier. The deposits would seem, in short, to have been formed in a glacial lake, the materials being washed into it chiefly from the retiring glacier.

At this stage of its history Scotland must have been a small Greenland or Spitzbergen. With its mountains snow-clad, considerable sheets of ice covering much of the high grounds—great glaciers occupying all the large mountain-valleys—and icebergs sailing away from the ice-front along almost the whole north and north-west coasts, it must have presented a thoroughly arctic aspect. The coasts were probably fringed, in winter at least, with an ice-foot, which, breaking up in summer, carried away much rock-débris: for the old beaches of the period often contain erratics which could hardly have been brought there by any other means. Thus fragments of chalk are not uncommon in the marine deposits of the Forth, as at Portobello and at Tyrie, and they occur also in those of Barry and Montrose. These erratics were probably carried from the coast-lands of Aberdeenshire and other regions farther north, where the boulder-clays, as we have seen, are often plentifully charged with chalk débris.

Of the flora and fauna that may have occupied the less desolate portions of the land at this time we have only scanty traces.[1] We know that arctic mosses flourished, and it is not unlikely that the coasts may have been the favourite haunt in summer of sea-birds, just as arctic coasts are now. But very few remains of birds have been obtained. It is the marine life that is best represented—and that, as we have seen, has an arctic facies. We note evidence to show that the waters of the North Sea were somewhat colder

[1] It is most probable, however, that the arctic plant-beds to be described in a later chapter really pertain to this horizon.

than those that laved the west coast of Scotland. Thus at Elie (Fifeshire) the fauna of the shell-beds is more pronouncedly arctic than that of the fossiliferous deposits in the Clyde basin. From this it has been inferred that the former may belong to an earlier date than the latter—to a time when the cold was severe. But this conclusion seems unnecessary, for a partially closed basin like the North Sea, open only to the north, and filled with floating ice, would in all probability have a lower temperature than the ocean that washed the western sea-board.

In a former chapter reference has been made to certain great lakes which came into existence during the decadence of the last general *mer de glace*. The relics of these, consisting of terraces, shelves, and broad flats of gravel, sand, and clay, wholly destitute of organic remains, are conspicuous in many parts of the Southern Uplands. Similar phenomena are associated with the relics of the particular glacial epoch now under review. I refer to the famous 'Parallel Roads' of Lochaber. These are horizontal terraces or shelves from 40 to 70 ft. broad, and inclined outwards from the hill-slopes at angles varying from 5° to 30°. They are well developed in Glen Roy, where they occur at the heights of 856 ft., 1,065 ft., and 1,149 ft. respectively above sea-level. Similar shelves are seen in some adjacent valleys, as in Glen Spean, Glen Gluoy, &c. All those valleys drain westwards into Loch Lochy. Various views have been entertained as to the origin of the terraces. Macculloch[1] and Dick Lauder[2] long ago suggested that they were the shore-lines of old lakes, the waters of which had been retained by great barriers of detrital matter. The same notion was strenuously upheld by Mr. Milne Home,[3] who failed, however, to convince geologists of the former existence of detrital barriers—not a trace of which is now visible. By others the shelves have been attributed to the action of the sea—a view at first supported but afterwards rejected by Darwin.[4] This explanation has been well set forth by Robert Chambers,[5] J. Nicol,[6] and

[1] *Trans. Geol. Soc. London*, vol. iv. p. 314.
[2] *Trans. Royal Soc. Edin.* vol. ix. p. 1.
[3] *Ibid.* vol. xvi. p. 395; xxvii. p. 595; xxviii. p. 93.
[4] *Phil. Trans.* 1839, p. 39.
[5] *Ancient Sea Margins.*
[6] *Quart. Journ. Geol. Soc.* vol. xxv. p. 283.

[. F. Campbell,[1] but is now generally abandoned in favour of he glacial lake theory first suggested by Agassiz,[2] and since vorked out with admirable skill by Mr. Jamieson[3] and Pro-essor Prestwich.[4] Mr. Jamieson points out that all the lens in which terraces occur have been invaded by ice oming from the region that lies west of the Great Glen. 'he ice-shed during an epoch of glaciation did not always xactly coincide with the present watershed. Owing › the greater accumulation of snow upon the West and orth-west Highlands the ice-sheet that covered those gions was enabled to encroach upon the territories lying to ıe east and south-east. Thus, as Mr. Jamieson has shown, ıis western ice filled Glen Gluoy, Glen Roy, and Glen pean, so that before the lakes in those valleys had come ıto existence, the ice-drainage of that district was directed ıto the valley of the Spey. The mass of ice lying over the Vestern Highlands being immensely thick would necessarily, s he remarks, linger on long after the thinner ice covering ochaber and the district to the east had melted away. nd as this region of thick ice lay right across the mouths ıe glens in which the Parallel Roads occur, glacial lakes ould not but come into existence in those glens. This ppears to be a not unreasonable conclusion. That the glens ı question were blocked by ice coming from the west and outh has been clearly established. But after revisiting ochaber I have been led to doubt whether the Parallel Roads were formed during the decay of the last general *mer e glace.* It seems to me more likely that they belong to ur 'third glacial epoch'—the epoch of district ice-sheets nd great valley-glaciers. We have seen that after the dis-olution of the last general ice-sheet another recrudescence f glacial condition supervened, during which the snow-line ı the Highlands ranged between 1,100 and 1,500 ft. With he snow-line at an elevation of 1,200 or 1,300 ft. the great alley now occupied by Loch Arkaig could not fail to be filled ith a massive glacier. Of its 90 square miles of drainage-

[1] *The Parallel Roads of Lochaber*, Nov. 22, 1877.
[2] *Edin. New Phil. Journ.* vol. xxxiii. p. 236.
[3] *Quart. Journ. Geol. Soc.* vol. xix. p. 235; xlviii. p. 5; xxi. p. 161; xxx. '. 317; xlviii. p. 5.
[4] *Phil. Trans.* 1879, p. 663.

area, 55 at least exceed an elevation of 1,500 ft., and the configuration of the entire district is eminently suited for the storage of snow—many capacious glens opening upon the broad and deep main valley. Moreover we must not forget that the region is at present included in the area of greatest precipitation ; and the probabilities are, as Mr. Jamieson has remarked, that in glacial times it was also a region of excessive snow-fall. Similar conditions must have obtained in Glen Roy and Loch Eil, so that it cannot be doubted that during the epoch of district ice-sheets an enormous flood of ice streamed from the western valleys into Glen More. To this would be added the supplies coming from Glen Nevis and from all the deep and capacious valleys that descend to the north from Ben Nevis. From these several sources ice must have flowed in sufficient abundance to fill the Great Glen up to a height sufficient to block Glen Roy and Glen Gluoy. There is not the slightest evidence to show that either of those glens has ever been occupied by independent glaciers comparable in size to those that streamed into the Great Glen. The only ice which has ever traversed them from end to end was that of the last great *mer de glace*—and this, as we know, flowed up and not down the glens. With the snow-line at 1,300 to 1,500 ft. it is quite impossible that Glen Gluoy could ever be occupied by one continuous glacier. The limited extent of its drainage-area and the orographical features of the district alike forbid the supposition. The entire gathering-ground does not exceed 14 square miles, fully half of which is under a height of 1,500 ft. There is only one place, indeed, at which we might have expected to meet with traces of local glaciation—namely, in Glenfintaig —and it is precisely here where local moraines put in an appearance. These, as I believe, indicate the presence of a small glacier which entered Glen Gluoy at the very time the glen was occupied by its glacial lake. It is possible also that a small local glacier may have come down to the head of the glen from the south—the presence of which would account for the discontinuity of the Parallel Road on that side of the glen. But this is merely a suggestion, for I have not visited the spot.

Glen Roy has a much larger drainage-area—not less than

0 square miles—of which rather more than half exceeds ,500 ft. in elevation. But the orographical features :e not such as would favour the formation of deep snow-ɜlds—there is no convergence of high-level valleys towards ιe head of Glen Roy. Consequently there could have been) concentration of local ice-flows, and therefore no formation a large trunk glacier when the snow-line stood at a height 1,300 to 1,500 ft. Yet we have evidence of the former 'esence here and there of small glaciers having descended e mountain-slopes into Glen Roy. This is shown by the currence of local morainic materials, and sometimes, as I ink, by interruptions in the continuity of the lake-beaches. milar appearances confront us in Glen Spean, which seem be explicable in the same way. Although my last visit the district was somewhat hurried, I yet saw sufficient to ɹd me to doubt that the origin of the Parallel Roads could ,te back to the last epoch of general glaciation. It is more 'obable, I think, that the highest of the beaches came into :istence at the climax of the epoch of district ice-sheets—at time when small local glaciers here and there reached the kes. The later terraces doubtless point to the successive wering of the ice-dams in the manner described by Mr. ɹmieson. My view, therefore, differs only in one respect om that so ably maintained by him.

CHAPTER XXII.

LATE GLACIAL AND POST-GLACIAL DEPOSITS OF SCOTLAND.

Peat-bogs—Trees, &c., occurring in and underneath bogs; submerged peat, &c. —Drift-wood in the deposits of the Carse-lands—Raised beaches and estuarine flats—Blown sands of maritime districts—River alluvial terraces and their correlation with marine deposits—Lacustrine alluvia—Organic remains.

THE accumulations which must next engage our attention carry on the story of the past from the close of our 'third' glacial epoch to the present. Hence they are usually termed by geologists the postglacial and recent formations, and comprise peat-bogs, raised beaches, blown sand, and alluvia. These will be described in the order they are here mentioned, not because that is strictly chronological—for some of the accumulations are of contemporaneous origin—but simply for convenience' sake.

Everyone is familiar with the fact that large areas in Scotland are covered with more or less thick coatings of peat. These are not confined to any particular region, but they certainly occur in greatest abundance in upland and highland districts, where they frequently extend over many square miles.

That a peat-bog is entirely composed of vegetable matter I need hardly say—that it has been formed by the growth and decay of successive generations of plants no one doubts: and these plants, moreover, as is well known, are still indigenous to the country. Such being the case, there may seem to be no difficulty in understanding how it comes to pass that we have peat-bogs. The plants which go to form these turbaries are still growing, and if we only allow them sufficient time, no doubt they will give rise to more peat-bogs. But when we begin to look a little more closely into

he matter, we find that we cannot settle the question quite) easily. It is well known that underneath the peat-bogs, ɔots, trunks, and branches of forest-trees and shrubs occur ı great profusion. Here, then, is a difficulty. The buried mber assuredly marks the sites of ancient forests. How id the peat come to overwhelm these? To discover this, is obviously necessary that we should first endeavour to scertain what kinds of trees are buried under the peat, and ɔw these are distributed through the country.

The Scottish bogs have yielded oak, pine, birch, hazel, der, willow, juniper, &c.—all of them species which are ven now indigenous to the country. There would appear, owever, to be an interesting exception to the rule, for it is ıid, on good botanical authority, that the cones of *Abies icea* (silver fir) have been dug out of the peat in Orkney— tree which is common in Norway, but not now indigenous Scotland. From the position occupied by the buried ees, it is positively certain that they actually grew in place. he stools are rooted in the old soil; the trunks, branches, vigs, and even the leaves and fruits, lie all about. Nay, ıore than this, each species is found rooted upon that par- cular kind of soil which it is known to prefer; thus pines ccupy the lighter gravelly soils, and oaks the heavier clays. gain, we find that the pine predominates in bogs at high- vels, while in those at lower levels the oak is more common.

Then, as regards the distribution of the ancient forests, it no overstatement to say that they occur everywhere. I now of few areas of lowland peat-bog in which they have not een detected; and this is not peculiar to the mainland, but ven characterises the little outlying islands. The visitor to ewis is startled to find amidst the desolation and sterility f its extensive moorlands the trunks of full-grown trees, onsisting of oak, alder, birch, and especially Scots fir. Nowadays the only trees in the island are those which the ate Sir James Mathieson, at great expense, coaxed to grow t Stornoway. Yet, in some of the islands of the Outer Hebrides, a few stunted stems of hazel, birch, and mountain- ısh may occasionally be seen clinging to the rocks, in places which are beyond the reach of sheep and cattle. The bare slands of Orkney and Shetland have also at one time

supported large trees, while of the mainland itself it is difficult to say what district has not waved with greenery. The bare flats of Caithness, the storm-swept valleys of the Western Highlands, the dreary moorland tracts of Perthshire and the north-eastern counties, the peaty uplands of Peeblesshire and the Borders, and the wilds of Carrick and Galloway, have each treasured up abundant relics of a bygone age of forests.

It would seem also that some of our trees had a greater vertical and horizontal range in old times than now. Mr. Watson gives 600 yards and upwards as the height reached by the Scots fir at present. But he 'has seen also small scattered examples at 800 or even 850 yards of elevation.' These last, however, he thinks had probably been planted. 'But that the pine,' he continues, 'has grown naturally on the Grampians at an equal elevation in former ages, is rendered certain by the roots still remaining in the peat-mosses of the high table-lands of Forfar and Aberdeen at 800 yards and upwards.'[1] Again, in Glenavon, Banffshire, there are peat-bogs nearly 3,000 ft. above the sea, with abundant roots of the pine;[2] and in the north of England they have been met with at a similar height.[3] The Scots fir now ranges from Perthshire into Sutherland within lat. 56°–59°, but in former times it must have grown indiscriminately throughout the length and breadth of Britain, since we meet with it in many of the English mosses, as well those of southern as of northern districts.

The common oak has a similar wide diffusion in the peat-bogs, and the same remark applies to other species. Nothing indeed is more common than to meet with buried trunks of very large dimensions, occupying levels and positions which are now in the highest degree unfavourable to the growth of timber; and this not only in the interior parts of the country, for great trees are frequently dug out of peat close to the sea-shore.[4]

[1] *Cybele Britannica*, vol. ii. p. 409.
[2] Sinclair's *Statistical Account of Scotland*, vol. xii. p. 451.
[3] Mr. Wynch, quoted in *Cybele Britannica*, *loc. cit.*
[4] *Edinburgh Philosophical Journal*, vol. xvii. p. 53; see also *Philosophical Transactions*, vol. xxii. p. 980; and the *Statistical Account of Scotland* (Old and New), *passim*.

Now and again the peat-bogs contain more than one forest-bed. Thus in the peat of Strathcluony three successive tiers of Scots firs were observed with peat between. In other places I have been told by peat-diggers that at the bottom of the bogs they usually get oak, and that when an upper stratum or tier of trees occurs, the common species is usually Scots fir. I have never myself seen such a succession in open section, but from what I have heard, the phenomena appear to be not uncommon. The Scottish peat-bogs, however, have not been studied by botanists and geologists so assiduously as those of the Continent, and they are therefore not so well known. The fact is that the working of the bogs for fuel in Scotland is not now carried on to any large extent, save in remote regions in the Highlands and islands. There is thus less opportunity for their study than there used to be when the great bogs of the Lowlands were being exploited. In the cuttings made for the Aviemore and Inverness Railway across the 'Mhoideach Mhor' or 'Big Moss,' several tiers of trees were disclosed. 'In one place, at a depth of about six feet from the surface, they came upon one tier of standing fir-trees with branching roots; below this, about twelve feet from the surface, another tier; and four feet further down still another—these tiers showing that during the ages since the moss began to form, three different forests must have existed, or four if the surface tree roots are taken into account. The bark on some of the trees was still quite visible, and stems of pines, twenty feet in length, were frequently met at great depths.' [1]

But one of the most noteworthy points in connection with the peat-bogs remains to be mentioned. They are frequently found to pass below the level of the sea. This peculiarity has been observed in many places all round the coasts. It is needless to describe these submerged forests in detail, but I may note a few localities where they have been seen. On the coast of the Bay of Skaill (Orkney) an acre of peat-moss containing roots and trunks of fir-trees was exposed during a storm by the washing away of the superincumbent sand.[2]

[1] *Dundee Advertiser*, May 12, 1894. It is to be hoped that we shall ere long have a careful description of this interesting section from some of the geologists of Inverness.

[2] *Edin. Phil. Journ.* vol. iii. p. 100.

Again, on the north coast of the island of Sanday (one of the Orkneys) decayed roots of trees are seen at ebb tide upon the beach at Otterwick Bay,[1] and the like occurs in the Bay of Sandwick, another of the same group of islands.[2]

In the sea at Lybster, and under the sands of Reiss in Caithness, Mr. B. N. Peach tells me he has seen sunk peat with large trees.

In the Bay of Findhorn, as Mr. Horne informs me, trunks of trees have been dredged up, and from all the evidence he could obtain he has no doubt that these indicate the site of an old 'submerged forest.'

A number of years ago, while some improvements were being made in the harbour of Aberdeen, a good many trunks of oak of large size were dug up, and their position showed that they had not been brought down by the river, but had grown where they were found.[3] In the parish of Belhelvie, in the same county, peat occurs under the sea-level, and is covered to a depth of ten or twelve feet with sand. Oak-remains appear in this peat, and from the fact that during storms large cubical blocks of peat are often cast on shore, it seems probable that the peat and its buried trees extend for some distance out into the bay.[4]

In the neighbourhood of Montrose a peat-bed has been described by Dr. Howden as occurring underneath a considerable thickness of estuarine and alluvial deposits. It is nowhere exposed at the surface, but has been reached in borings and artificial cuttings. At one place it was met with at a depth of twenty feet—the greater part of the section being below the level of the sea. The peat 'rested almost directly on glacial marine clay, and contained stems of trees, leaves of bog-plants, and numerous seeds, most resembling those of some *Juncus*.' The same observer informs us that fragments of peat containing many elytra of beetles were found in the sand at a depth of twenty feet below the surface during the construction of a new dock at Montrose.[5]

In the Carse of Gowrie it is well known that trunks of

[1] Sinclair's *Statistical Account*, vol. vii. p. 451; Barry's *Orkney Islands*.
[2] *New Statistical Account*.
[3] *Ibid.*
[4] *Ibid.*
[5] *Trans. Edin. Geol. Soc.* vol. i. p. 144.

oak, willow, and other trees lie buried at depths varying from twenty to twenty-seven and even to forty feet. All these are really at or below the sea-level. At the Braes of Monorgan and Polgavie, the river Tay has cut down through the Carse-land and exposed a bed of peat four feet thick, containing trunks of oak, fir, alder, and birch, the roots of which penetrate an old soil. This peat, which now forms the bed of the river, is buried below some seventeen feet of alluvial matter, throughout which a good deal of vegetable débris occurs; towards the top of the section, cockles, mussels, and other sea-shells make their appearance. It is said also that in sinking wells in the Carse-land, 'deer's horns, skulls, and other bones' have frequently been found, along with the remains of the trees mentioned above.[1]

At Flisk, on the south side of the Firth of Tay, submerged peat has been traced along the beach in one place for a dis-

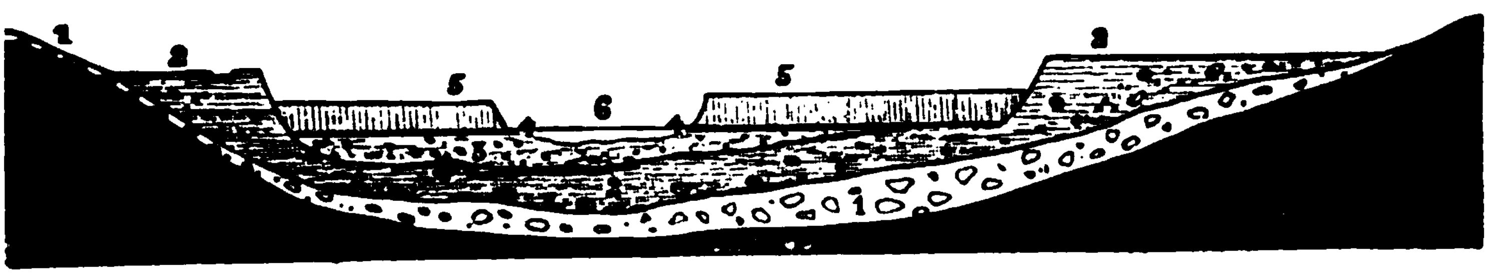

Fig. 62.—Section across Carse of Gowrie. 1. Till; 2. Clay, &c., of 100-ft. terrace; 3. River-gravel and sand; 4. Peat-bed; 5. Carse-clay of 45–50-ft. terrace; 6. Recent alluvia.

tance of three miles, and in another for no less than seven miles. It contains hazel and hazel-nuts, and what appears to be alder, and the roots are said to occur in places at ten feet below the limits of the full tide.[2] The position occupied by the buried peat in the Carse of Gowrie is shown in the accompanying section. It will be observed that the bed in question rests upon a variable thickness of sands and gravels, (3), which are obviously of fluviatile origin. When these are absent it lies directly upon the marine clays (2) of the 100-ft. terrace. An examination of this interesting bed in the valleys of the Tay and Earn shows that, although in the lower reaches of the Tay it descends below the sea-level, it gradually rises to a higher level as it is followed up the valley, so that at Perth, in the valley of the Tay, and at

[1] Sinclair's *Statistical Account*, vol. xvi. p. 556.
[2] *Trans. Roy. Soc. Edin.* vol. ix. p. 419.

Easter Balgour, in the valley of the Earn, it reaches six to nine feet above high-water. It seems to be very generally present throughout all the wide Carse-lands, and was cut through under the bed of the estuary at Dundee, in the operation of founding the piers of the Tay Bridge. The peat is generally highly compressed, and readily splits into laminæ, on the surface of which many small seeds now and again appear, together with occasional wing-cases of beetles. As a rule the bed is sharply marked off from the silt and clay which immediately overlie it, but occasionally this is not the case—the peat dovetailing to some extent with the lower portions of those deposits. In some places large trunks of pine are seen lying upon and in the peat, and having all the appearance of drift-wood. At Friarton, Perth, an ancient dug-out canoe of Scots fir occurred on the same horizon. It lay upon its bottom underneath the whole thickness of the superjacent clay.[1] That this peat indicates a former land-surface is proved by the fact that the old soil upon which it rests is usually more or less crowded with roots. At the same time it is obvious, from the appearance of the vegetable débris, that no inconsiderable proportion of this material has been drifted down the valley. The fact that the upper surface of the peat in some places contains layers of silt, and that isolated twigs, branches, and trunks are sometimes scattered through the lower three or four feet of overlying clay and silt, sufficiently demonstrates that all the materials which go to make up the peat-bed did not grow *in situ*.

In the estuarine deposits of the Forth drifted vegetable débris occurs under like circumstances. The Carse-lands of Falkirk and Stirling are, as we shall see presently, of the same character as those of the estuary of the Tay. In many places they contain much drifted wood, consisting of the trunks, branches, and twigs of birch, hazel, pine, and oak. Large trunks likewise occur in the ancient alluvia of such rivers as the Esk—alluvia which are of the same age as the estuarine beds of the Carse-lands.[2] It may be noted also

[1] The *Scottish Naturalist*, vol. v. p. 1. For further details see *Prehistoric Europe*, chap. xvi., and the references given there.

[2] *Proc. Roy. Soc. Edin.* 1883–84, p. 745.

that a thin bed of peat may be seen at low water on the sea-beach a little to the east of Largo.

In the islands of the Hebrides the same phenomena may be studied. At Pabbay, for example, peat with large trees is exposed at ebb of spring tides, and in Harris, where alluvial deposits have been undermined and cut back by the sea, 'a rich loam or black moss' is discovered. And this is said not to be peculiar to Harris, but characteristic of all the low-lying sandy shores of the Long Island,[1] as in North Uist and Vallay, at both of which places submarine peat and trees occur.[2] Again, on the north-west coast of Tiree, and here and there in Coll, the same appearances recur.[3]

Nor are similar phenomena wanting on the western shores of the mainland, for trees and peat have been found under low-water mark at Loch Alsh,[4] while at Oban the bed of the sea, not less than twenty feet deep, is said to be covered with peat in some places.[5]

Before attempting to account for the foregoing facts relating to the peat-bogs of Scotland it will be more convenient to consider first the phenomena of what are known as *Raised Beaches*. In the preceding chapter I discussed the origin of the 100-ft. terrace, and showed that Scotland during the epoch of district ice-sheets was submerged to the extent of 100 to 130 ft., or thereabout. No marine deposits of later date than that submergence have been met with at a greater height than 50 ft. or so. It is true that shelves and terraces excavated in solid rock occur now and again in maritime districts up to heights of 200 or 300 ft., but these all pertain to glacial and interglacial times. If they had been formed in subsequent ages we ought certainly to meet with traces of a like amount of depression in the interior of the country—for the sea which had leisure to excavate rock-terraces when the land was 200 or 300 ft. lower than now, must have had time also to cover the submerged tracts with shelly sands, gravels, &c. But nothing of the kind occurs. Dr. Robert Chambers, in his interesting work, 'Ancient Sea

[1] Sinclair's *Stat. Acc.* vol. x. p. 373.
[2] *Ibid.* vol. xiii. p. 321.
[3] *Edin. Phil. Journ.* vol. vii. p. 125.
[4] *Op. et loc. cit.*
[5] Anderson's *Practical Treatise on Peat-Moss*, p. 150.

Margins,' has noted a number of what he thought were old raised beaches at heights approaching and even exceeding 1,000 ft. But none of these can be relied upon as evidence of wave-work. The shelves on the Eildon Hills and the West Lomond Hill are cases of atmospheric erosion, and similar markings occur on every hill-side where the rock-outcrops yield horizontal or approximately horizontal ledges. The examples quoted by the same author from the upper reaches of the valleys of the Clyde and Tweed are, some of them, flutings formed by the action of ancient glaciers, others are merely river-deposits, while very many of the terraces at much lower levels, as for example those at Peebles, Kelso, &c., are also of fluviatile origin. Again, the Parallel Roads of Glen Roy, which have formed so fruitful a source of controversy, are no longer recognised as ancient sea-margins, but as lake-terraces. Indeed, when we consider the conditions under which the great glaciers disappeared, we cannot but be chary of ascribing any deposits met with in the interior of the country to the action of the sea. Beds of gravel, sand, and silt occur in such extraordinary positions in the Alps, and other highly glaciated regions, that we may well pause before deciding upon the marine origin of any such unfossiliferous deposits occupying similar positions in our own country.

If we have thus reasonable doubts as to the marine origin of such shelves and terraces as may sometimes be detected in the interior of the country, we can have little hesitation in ascribing to the action of the sea those platforms of rock, and more or less broad terraces of silt, sand, and gravel, which in so many places skirt the coasts. The terraced deposits are often plentifully stocked with the shells of the common littoral molluscs, and the whole aspect of the accumulations leaves one in no doubt as to their being ancient sea-margins. When such a terrace is followed inland from the coast it is usually found to abut more or less abruptly against a steeply-sloping bank or a well-marked cliff of hard rock, at the base of which we may often observe caves and hollows which are evidently the work of the sea.

On the east and west coasts of Central and Southern Scotland two well-marked raised beaches occur. Of these the

igher and older reaches a height which rises between 45 nd 55 ft. above the present sea-level. This old beach often xtends continuously, and with some breadth, for considerble distances, but as a rule it appears for the most part only ere and there in what seem to have been once sheltered ays. Nevertheless, on projecting promontories we not inrequently find it represented by a shelf cut in the solid rock. The terraced deposits consist principally of gravel and sand, nd frequently contain shells belonging to existing British species, associated with which there have occurred certain shells that seem to be now restricted to more northern atitudes.[1]

But by far the most important development of this old sea-margin is met with in the estuaries of the Tay and the Forth. In the section (Fig. 62, p. 291) the position of the Carse-deposits is shown (5). The upper surface of these leposits reaches a maximum height of 45 ft. or thereabout, nd as they are continuous with the 45 to 50-ft. beach on the open sea-coast, and moreover contain sea-shells, their marine origin is beyond question. They consist chiefly of clay and silt, and vary from ten or fifteen up to fully forty feet in hickness. When followed up the valley they pass into luviatile terraces of silt, sand, and gravel. In the low eaches of the Tay Valley the Carse-clays have yielded *Scroicularia piperata.* Higher up the valley they contain as a ule no shells of any kind; but a few years ago I got thin yster-shells in the deposits at Perth. The clays are usually estitute of stones; now and again, however, small erratics ccur, some of which measure six inches across. Excepionally, larger blocks are met with; the largest I have seen eing some four feet in diameter. It must be noted, howver, that stones and boulders are very rare—the deposits re essentially stoneless. Moreover, although a considerble proportion of the materials consists of true clay, et by far the larger mass is composed of silt and loam. These old estuarine accumulations, it will be remembered, verlie the peat-bed already described, and contain,

[1] Mr. Gwyn Jeffreys, *British Association Reports*, 1862; A. Geikie, 'On the lacial Drift of Scotland,' *Trans. Geol. Soc. Glas.* vol. i. pt. ii. The latter uthor suggests that possibly these more northern forms may have been washed ut of deposits of glacial age.

especially in their lower portions, abundant drifted vegetable débris.[1]

In the upper reaches of the Firth of Forth the 45 to 50-ft. beach is well developed. In the neighbourhood of Falkirk and Stirling the deposits of this level form the well-known Carse-lands—extensive sheets of mud, silt, clay, and sand, containing in many places recent sea-shells, such as *Cardium edule, Ostrea edulis, Cyprina islandica, Littorina littorea, Trophon clathratus, Buccinum undatum,* &c. The upper limits of this great flat are well marked out by bluffs and banks—the old coast-lines. Of its marine origin, therefore, there can be no doubt. Now, throughout the Carse-deposits there occurs at various levels much drifted vegetable débris, consisting of the trunks, branches, and twigs of such trees as birch, hazel, pine, and oak, and associated with these oyster-shells often appear in abundance. Remains of whale,[2] dug-out canoes, and rude implements and weapons have likewise been discovered in the same deposits, while along what was the old shore-line kitchen-middens are frequently met with. All the middens, as Mr. Peach observes, 'occur on the bluff itself or just at its base, as if, when it was the limit of high-water, the people who formed the middens, after searching the shores during low water, had retreated thither to enjoy their feast while the tide covered their hunting-ground.'[3] It is noteworthy that when those Carse-deposits are followed up the valley, they are found rising with a gentle gradient, until eventually they pass into fluviatile deposits of sand and gravel. The evidence shows that at a time when the sea washed the 45 to 50-ft. level the River Forth, flowing in much greater volume than at present, carried down to its estuary enormous quantities of drift-wood, some of which got bedded in the sand of the lower reaches of the river, some in the silt and mud of the estuary, while much no doubt found its way eventually out to the open sea.

[1] For a fuller description of the Carse-deposits of the Tay and Earn, see *Prehistoric Europe*, chapter xvi.

[2] Sir William Turner informs me that the skeletons of large whales, which from time to time have been found embedded in the Carse-deposits of the Forth valley, so far as they have been critically examined, have been determined to belong to the genus *Balænoptera*, and are not examples of the *Balæna mysticetus*, or Greenland whale, as is generally believed.

[3] *Mem. Geol. Survey of Scotland*, Expl. of Sheet 31.

In these estuarine deposits and the raised beaches of the)pen sea-coast with which they are continuous we are dealing ınquestionably with an old sea-level. It is obvious, also, hat this condition of partial submergence must have endured or a considerable time. Yet when we come to examine the oasts of the Northern and Western Highlands, few traces f the 45 to 50-ft. beach are seen. We can hardly suppose that he depression did not affect those regions ; for although few elics of that submergence remain, yet here and there they re conspicuous enough. They are seen, for example, on the hores of Loch Carron, and of Lochs Eil and Leven at Ballahulish, and in Kerrara, Lunga, Jura, Oronsay, and Colonsay.[1] 'hey are seldom, however, developed at the heads of the reat sea-lochs of the mainland. Here and there they do ccur, and when this is the case, it sometimes happens that hey are capped by moraines. Thus at the foot of Glen 'hraill (Sutherland), Mr. Hinxman found well-formed ıoraines reposing on the 50-ft. beach at the distance of bout three-quarters of a mile above the head of Loch 'orridon.[2] It seems highly probable, therefore, that the equent absence of the 45 to 50-f beach from the heads of ıe large sea-lochs is to be accounted for by the presence ıere of considerable glaciers.[3]

It is to this stage that I would assign the lake-basins hich occur towards the heads of many mountain-valleys, well as the large majority of corrie-lakes that are met ith up to a height of 2,400 ft. or thereabout. As we have en, these lakes and the terminal moraines which appear in ıeir neighbourhood indicate for the snow-line of the epoch ı average elevation of 2,500 ft. In the Western and orthern Highlands, however, it seems hardly to have risen ɔove 2,100 to 2,300 ft.

But by far the best preserved and most interesting of the d raised beaches is that which occurs at a height of 25 to) ft. above the present mean-tide mark in the Firths of ay, Forth, Clyde, and Solway, and generally both on the ıst and west coasts of Central and Southern Scotland. That ıe sea stood at this level for a considerable time may be

[1] *Trans. Geol. Soc. Glas.* vol. vi. p. 163.

[2] *Trans. Geol. Soc. Edin.* vol. vi. p. 249. [3] *Prehistoric Europe*, p. 411.

inferred from the amount of work it was able to perform. Broad platforms have been hewn in strata of sandstone and other and often harder rocks which formed the sea-margin; cliffs have been cut back, and caves have been hollowed out at their base by the action of the waves. Sometimes the old beach consists of only a more or less narrow ledge sawn into the face of a steep rock-slope or cliff, and showing sea-worn stacks and hollows; at other times it forms a wide flat, two or even more miles in breadth. It is upon these low-level beaches that the greater number of the Scottish seaports and fishing-villages stand. The lower reaches of the great estuarine flats of the Tay, the Forth, the Clyde, the Nith, and others, all belong to the period of the 25 to 30-ft. beach-level, but owing to the working of the rivers, it is often difficult in such regions to distinguish between the deposits of the 45 to 50-ft. beaches and those of later age. The rivers in their many windings have ploughed down through the Carse-clays of the higher level, and rearranged these in broad flats and terraces, which often merge into the beaches of the 25 to 30-ft. level. This is particularly the case in the Carse of Falkirk, and it may be observed also in the Carse of Gowrie.

The silts, clays, and sands, &c., of which this beach is composed have, in many places, yielded abundance of shells —all of which, without a single exception, are still living round the coasts. Relics and remains of man, such as canoes, have also been obtained. Most of these canoes are formed of single trees—'dug-outs'—but others indicate greater skill in construction. It is highly probable, however, that many of the 'finds' recorded from the Carse-lands at heights of 30 ft. and under are really from the deposits of the 45 to 50-ft. beach, for the later 'beach' is often a mere terrace of erosion excavated out of the older accumulations.

No decided traces of ice-action have been detected in the deposits belonging to the 25 to 30-ft. raised beach. It is true that, in the clay-pits on both sides of the Forth at this elevation above the sea contorted bedding is a common occurrence, but these contorted clay-beds belong unquestionably to the 100-ft. terrace—the 25 to 30-ft. beach is merely cut into them, and now and again the later accumulations

of gravel and sand may be seen lying upon the denuded clay-beds, which have evidently suffered considerable erosion. Here and there large boulders rest upon the raised beach, but they have plainly been derived from the denudation of the boulder-clay. Boulders are scattered along the present beach in exactly the same way. The observer has, therefore, to be on his guard lest he should include among the deposits belonging to the 25 to 30-ft. beach every superficial accumulation that may chance to occur at that elevation. He must always remember that the beach is not entirely a terrace of deposition—but over wide districts is merely a shelf, broad or narrow as the case may be, cut out of pre-existing deposits of clay, sand, and gravel, and sometimes out of solid rock.

Of the *Blown Sands*, which are met with here and there along the coasts, it hardly falls within the scope of this work to say more than a few words. They occur generally on low-lying shore-lands, and very often at or near where a large river enters the sea. They frequently form long chains of dunes that extend in directions parallel to the coast-line. The Tent-Moor, between Tayport and the mouth of the Eden, is the best example of the kind which I have seen. The ridges there are wonderfully persistent and well defined. In other places, as at Stevenston on the Ayrshire coast, they form irregular hummocks and banks. Some of the most extensive accumulations are found along the shores of the Moray Firth, and Mr. Jamieson thinks that these have probably some connection with the rivers entering the sea in their neighbourhood—the sands of Culbin, for example, having been derived in great measure from the sand brought down by the Spey, the Findhorn, and the Nairn.[1] But in many instances they appear rather to be derived from the denudation of pre-existing glacial deposits. Such is certainly the case with those on the shores of Ayrshire and the Firth of Forth. So much is this so, that it is often impossible to draw a line upon the map between recent blown sand and sand belonging to the glacial series. Blown sands are certainly very often connected with the great river-valleys, but this appears in most cases that I have seen

[1] *Quart. Journ. Geol. Soc.* 1865, p. 192.

to be due to the fact that those river-valleys contain abundant deposits of glacial age which, upon the low coast-lands at their mouths, become exposed to the combined action of the sea and the wind. So again, in the case of the Outer Hebrides, the Atlantic coast-lands of which are in many places covered with blown sand, there can be no doubt that this is derived from the glacial detritus with which the floor of the sea in that region must be deeply covered.

The last of the so-called postglacial deposits which I shall describe are the *Fresh-water Alluvia*—fluviatile and lacustrine accumulations. While reviewing the evidence derived from the Carse-deposits of the 45 to 50-ft. level, I mentioned the fact that when these are followed inland they eventually merge into high-level river-gravels and sand. This is particularly well seen in the valley of the Tay above Perth. We there find the old river-terraces forming prominent features. Two terraces are especially conspicuous, the upper one being continuous with the 100-ft. beach, and therefore dating back to the epoch of district ice-sheets and great valley-glaciers, while the lower, as I have just mentioned, is the fluviatile continuation of the 45 to 50-ft. estuarine accumulations. Both may be followed a long way up into the heart of the Highlands, appearing not only in the Tay valley, but in the valleys that are tributary to it. The materials of which the terraces are composed are chiefly gravel and sand—the gravel being in many places extremely coarse. Indeed, not infrequently the deposits consist of a tumultuous mass of shingle and rounded boulders. Mr. H. C. Sorby many years ago noticed the evidence in these terraces of oscillating currents, and came to the sagacious conclusion that they had been 'produced by the combined action of the river and a tidal sea, when the elevation of the land was such as to cause it to stand at a level corresponding to their several altitudes.'[1] In many other Scottish valleys the old river-terraces bear a similar relation to former sea-levels, but the connection between the river-gravels and the raised beaches is seldom so clearly seen as in the basin of the Tay. It is thus frequently quite impossible to assign our old fluviatile deposits to any particular horizon in the glacial

[1] *Edin. New Phil. Journ.*, new series, vol. iv., October 1856.

or postglacial series. In the lower reaches of the larger valleys, as in that of the Tweed, we can have little hesitation, indeed, in correlating the terraces that rise to heights of 60–80 ft. above the present river to the period of the 100-ft. depression, while those that occur some thirty or forty feet lower are probably of the same age as the 45 to 50-ft. beach, while at still lower levels some of the river-flats may well be contemporaneous with the beaches of the 25 to 30-ft. level. But in the upper reaches of the valleys it is usually impossible to assign the old alluvial flats to any particular horizon, except in cases where the valleys head in regions which nourished snow-fields and glaciers in the later stages of the glacial period. For in all such valleys the fluvio-glacial gravels are characterised by their general coarseness and greater elevation. One may recognise in many of the larger valleys (those, for example, of the Tweed, the Clyde, and the

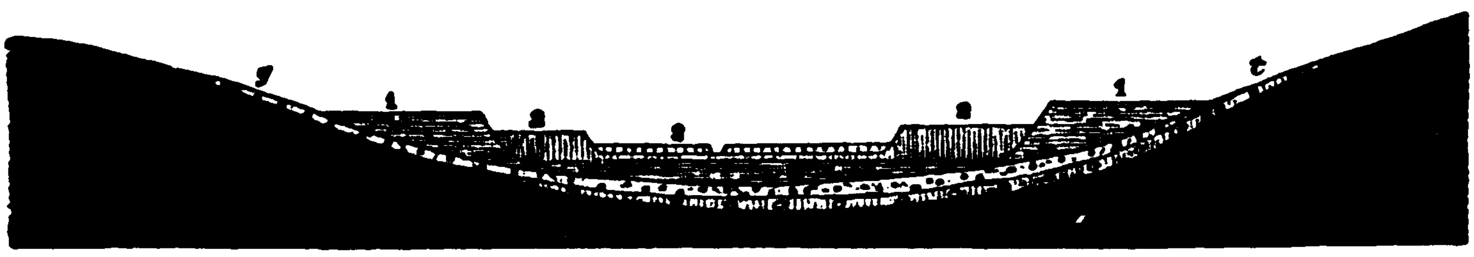

Fig. 63.—Late glacial and recent River-gravels, &c. *t*, Till; *g*, Fluvio-glacial gravels; 1, 2, 3, Successive terraces.

Tay) three principal river-terraces, occurring at successively lower levels. Sometimes all three may be seen in one place, more frequently two are present, and often enough only one, the most persistent flat being the lowest or youngest. The accompanying section shows the relation of the terraces to each other and the underlying boulder-clay with its associated glacial gravels. The highest terrace (1) is frequently absent, and when present often shows a much denuded aspect, although occasionally it is very well preserved. It is usually composed of coarse sand, grit, gravel, and shingle, and often contains many large water-worn boulders. In the lower reaches of the broad valleys, however, its ingredients are commonly finer grained, sand predominating. The materials of the second terrace are of essentially the same character, but perhaps hardly so coarse. The lowest flat consists of more orderly arranged deposits of gravel, sand, and silt, which are quite comparable to the accumulations

now forming. The highest terrace represents, as I think, the torrential deposits of our epoch of district ice-sheets and great valley-glaciers, when the land stood 100 to 130 ft. lower than now. The second terrace, again, was probably contemporaneous with our epoch of small local glaciers, when the sea stood at the 45 to 50-ft. level. The terraces at lower levels—for there are often several of these—belong to the later stages of our history. The two higher terraces are usually devoid of organic remains of any kind. Indeed, I have never detected any trace of these in the oldest; in the second terrace, however, large trunks of oak, pine, and vegetable débris have sometimes been met with. But this was only in places where the fluviatile deposits merged into the estuarine accumulations of the 45 to 50-ft. level, as in the ancient alluvia of the Esk at Musselburgh.

I have already described the chief types of lakes in Scotland, and have shown how not a few of these have been silted up by streams. Such occurrences are probably more common than we have any idea of—for it is always difficult to prove that a wide flat of alluvial land marks the site of an ancient lake. The barriers that formerly held in the water have either been swept away, or are buried deeply under recent deposits. Such is the case with not a few rock-basins, where the lower lip of rock is often concealed below silt, sand, or gravel. And it is only by boring that this fact can be demonstrated. I have referred to two such cases, namely, Bogton Loch, near Dalmellington, and St. Mary's Loch in Peeblesshire, which are two rock-basins in the course of being filled up. Others, again, as I have remarked, have been completely obliterated by the pouring into them of sediment. Very few of the fresh-water lakes and sea-lochs do not show more or less extensive flats opposite the mouths of the streams and rivers that flow into them; and even where no such flat ground appears, the soundings yet show that a *cône de déjection* is gradually increasing below the surface of the water. This is specially the case, of course, when the lakes are deep.

In the lowland districts there are numberless little sheets of alluvium and peat that mark the sites of shallow pools and lakelets. Many of these, especially in Ayrshire, rest in

ows of the till, and some in superficial depressions of t sand and gravel. They have not been silted up by ams, but by the gradual washing down of the banks and es that surround them, under the long-continued action ain and frost. And, indeed, I know hardly anything e calculated to impress one with the importance of these arently insignificant agents of waste than the phenomena nected with the obliterated lakelets referred to. The osits that fill them up are often several yards in thick- , twelve and fifteen feet being no uncommon depth. m and loamy clay (the latter sometimes used for brick- ing) are the prevailing ingredients, but not infrequently se contain intercalated beds of peat and decayed trees, ch have evidently grown *in situ*. The trees are principally ows and alders, but at the bottom oaks often appear rooted he subjacent glacial clays.

To Mr. J. Bennie of the Geological Survey of Scotland are indebted for the first discovery of arctic plants in old alluvia of the Lowlands. The alluvia in question icate the former existence of small lakes, which occupied lows in the surface of the upper boulder-clay. They have n noted at Hailes Quarry and Corstorphine near Edin- gh, in the neighbourhood of Camilla Castle, Auchtertook, elsewhere. The arctic plants come from the basement- osits of the old lakes, and have been determined by Mr. ment Reid. Amongst them are dwarf birch (*Betula nana*), lows (*Salix polaris*, *S. herbacea*, *S. reticulata*), *Dryas ipetala*, and several other existing arctic and boreal species. ng with these occurred in great abundance *Apus glacialis* living form of phyllopod which is now found only in h-water lakes in Greenland and Spitzbergen. At Hailes arctic plant-bed was overlaid by silt containing plentiful aains of *Potamogeton*, various mosses, and patches of peat of seeds of potamogeton, bog-bean, and grasses. Animal was represented by a few fresh-water and land-shells, eral ostracods, *Daphnia*, &c. Above this silt came eight en feet of coarse sand, gravel, and silt in which hazel-nuts, rns, alder seed-cones, and stones of fruits abounded, together h much drift-wood, such as twigs, bark, and occasionally e trunks, eight or ten feet thick. In the old lake at

Corstorphine the uppermost deposits consisted chiefly of shell-marl, varying in thickness from two to twenty feet, and overlaid by six or seven feet of sand and gravel. In old 'Lake Dronachy' near Camilla Castle, the succession, as Mr. Bennie informs me, is reversed—the shell-marl in this case being overlaid with brown earth containing the arctic flora with *Apus glacialis*.[1] Not a few old lake-beds are found to be in large measure filled up with marl, consisting of the remains of innumerable fresh-water shells of indigenous species. Many examples of this occur in Forfarshire, where they were long ago studied by Sir Charles Lyell and others.[2] It is highly probable, as Mr. Bennie remarks, that arctic plants will yet be found in the bottom-deposits of all such ancient lakes.

In our lacustrine alluvia, and in low-level river-deposits, mammalian remains have frequently been discovered. Among other forms we get *Bos primigenius*, *B. longifrons*, wild boar, red deer, fallow-deer, roebuck, elk or moose-deer, Irish elk, reindeer, goat, wolf, wild-cat, fox, beaver. The *Bos primigenius*, or urus, is now extinct, but is believed to be represented by the white cattle of Chillingham and Hamilton, and our present domestic breeds. *Bos longifrons* is also extinct, but from it some of our domestic cattle may have descended.

The true elk (*Cervus alces*), which ranges over the northern regions of America and Asia, from latitude 45° northwards to the shores of the Arctic Sea, but in Europe does not come farther south than the 64th degree of latitude, formerly wandered over all Scotland, its remains having been found in alluvial deposits, as well in northern and central as in southern counties.[3] But there appears to be only one instance on record where remains of the Irish deer have occurred in these deposits, namely, in a marl-bed at Maybole in Aryshire.[4] The reindeer is also rarely met with,[5]

[1] J. Bennie, *Annals of Scottish Natural History*, January 1894.

[2] *Trans. of Geol. Soc.* vol. iv. p. 305. *Ibid.*, second series, vol. iii. p. 73.

[3] *Proceedings of the Society of Antiquaries of Scotland* (Dr. J. A. Smith), vol. ix.

[4] *New Statistical Account of Scotland*, vol. v. p. 353.

[5] The most interesting find of reindeer remains in Scotland is that made by the late Mr. Macfie of Dreghorn in a rock-fissure at Green Craig in the Pent'and Hills. The bones were identified by Mr. J. Simpson, of the Anato-

but there can be no doubt that it likewise was formerly a native of Scotland;[1] some writers, indeed, relying on a statement of Torfaeus, think that it may have survived in the extreme north down to the twelfth century. Wolves and beavers, though no longer natives of Scotland, were certainly so within historical times. Of the other animals mentioned, nothing need be said here; they are all forms eminently characteristic of a temperate climate.

It is remarkable that nowhere in deposits of later age than the upper boulder-clay have we any trace in Scotland of the great pachyderms, the remains of which occur so frequently in certain river-gravels and cave-accumulations in England and the Continent. All the remains of the mammoth yet detected have appeared either in beds that underlie or are intercalated in our boulder-clays, or else they have occurred as erratics in the actual till itself. There is a vague mention of the horn of a rhinoceros having been dug up in marl at the Loch of Forfar,[2] but I fear no reliance can be placed upon it.

The oldest relics of man in Scotland are met with at the bottom of the Carse-clays of the 45 to 50-ft. level. Stone implements of Neolithic types turn up everywhere, and to give merely a list of the places where they have been detected would be to enumerate every district in the country, not even excepting the outlying islands. They occur either at the surface of the ground, or embedded below peat, or buried in the fresh-water and marine alluvia of the 45 to 50-ft. level, and they frequently appear associated with the remains of some of the animals referred to above. We cannot assign them to an older date than the Newer Stone period of archæologists, not a single relic of the Older Stone period having yet been met with north of the Tweed.

mical Department, University of Edinburgh. They were associated with remains of horse, reindeer, and wolf (*Trans. Edin. Geol. Soc.* vol. v. p. 294). There is no evidence to fix the geological horizon of this ossiferous breccia. It is probably, as Mr. Henderson remarks (*op. cit.* p. 302), of later date than the general glaciation of the district. I suspect it is older than any of our truly postglacial alluvia, and that it may not unlikely pertain to the same stage as the arctic plant-beds. It may even date to a somewhat earlier stage—namely, to the close of the interglacial epoch that passed away on the advent of the district ice-sheets.

[1] *Proc. Soc. Antiq. Scot.* vol. viii. p 186.

[2] *Edin. Phil. Journ.* vol. viii. p. 307; *Memoirs Wernerian Society*, vol. iv. p. 582; vol. v. p. 573.

CHAPTER XXIII.

LATE GLACIAL AND POSTGLACIAL DEPOSITS OF SCOTLAND—*continued.*

General conditions during epoch of 100-ft. beach—Great forests of last inter-glacial epoch—Partial submergence with cold and humid conditions—Local glaciers in Highlands--Decay of forests and growth of peat—Re-elevation of land with return to forest-conditions--Renewed submergence with relapse to humid conditions—Small local glaciers—Last elevation of the land—Passage from postglacial times to present—General summary of glacial, interglacial, and postglacial succession in Scotland.

HAVING in the preceding chapter discussed the general character of the so-called postglacial and recent deposits of Scotland, I must now review the facts and endeavour to indicate the succession of events which followed after the close of our 'third' glacial epoch.

It is obvious, in the first place, that the various accumulations we have been studying must to some extent be contemporaneous. Thus we can hardly doubt that the growth of peat, the deposition of river- and lake-alluvia, and the formation of estuarine beds and sea-beaches must have been carried on simultaneously. I have discussed the evidence of each separately, simply to avoid confusion. We must now see how far it is possible to correlate that evidence; but before doing so it will be well to glance back for a moment at the conditions that obtained during the epoch of district ice-sheets and large valley-glaciers. We have seen that the deposits of the 100-ft. beach, the high-level terraces of our river-valleys, and the arctic plant-beds are the only conspicuous evidence of that epoch encountered in the Lowlands. In these low-lying districts many patches of ancient alluvia occur which we are at present unable to assign to any particular horizon. All we know is that since the time of their deposition considerable changes in the features of the land have taken place—changes brought

about by the long-continued action of rain, frost, and running water. Some of these, as I have already indicated (see p. 266), may date back to the genial interglacial stage that preceded the advent of our district ice-sheets. There is nothing unreasonable in this suggestion, for during that interglacial epoch streams and rivers and lakes must have existed, and alluvial deposits must have been laid down. No great ice-sheet has invaded the Lowlands since then, and although much denudation was doubtless effected by the torrential waters of the succeeding glacial epoch, and by the streams and rivers of later times, still it is improbable that all the alluvial relics of the interglacial epoch in question have been demolished. When the deposits underlying our deeper peat-bogs and certain other old alluvia have been carefully scrutinised, I can hardly doubt that we shall detect the equivalents of the younger interglacial beds of the Baltic coast-lands—those, namely, that underlie the 'diluvium' of the last great Baltic glacier. There are many patches and shreds of old alluvia met with in the Scottish Lowlands which have all the appearance of great age—implying, as they do, conditions of surface-drainage which no longer obtain. Reference has already been made to the occurrence at Maybole of a marl-bed from which have been obtained remains of the great Irish deer. It is remarkable that this species should occur so abundantly in the old alluvia of Ireland, and yet be so meagrely represented in those of Scotland—for Maybole is the only locality from which it has been recorded from alluvial deposits. Its rarity in Scotland can hardly have been due to any difference of climate between the two regions. Probably the conditions for the entombment and preservation of the animal were more favourable in Ireland than with us. The megaceros-beds of the sister island, as will be pointed out in the sequel, appear to belong to a distinct horizon, and to be older than the great peat-bogs with their buried timber. They belong, as I think, to the interglacial stage that preceded the advent of our district ice-sheets; and if this be so, it is not improbable that the Maybole marl-bed may be a relic of the same epoch. At all events, now that we know that such an interglacial epoch supervened after the disappearance of the last general *mer*

de glace (upper boulder-clay) we may reasonably expect to meet with alluvia of that age in the Lowlands of Scotland. Hitherto the postglacial age of the peat-beds and alluvia of those regions has been taken for granted, but they must be more critically examined before we shall be justified in assigning all to so late a date.

The recent discovery of arctic plants in certain old alluvia near Edinburgh and elsewhere must set us on our guard against inferring that all our superficial accumulations of freshwater silt, sand, &c. are necessarily of recent age. The ancient alluvia with their arctic flora must be older than the drift-peat and timber that underlie the Carse-deposits of the 45 to 50-ft. level, and are probably relics of our 'third glacial epoch'—when the low grounds of Scotland experienced a climate like that of Labrador and South Greenland. At that period, as we have seen, district ice-sheets covered our mountain-areas and flowed out for long distances upon the surrounding low grounds, while icebergs were calved at the mouths of our great sea-lochs. The sea then covered much of our low-lying tracts, the land being submerged for more than 100 ft. An arctic fauna lived round our coasts, which were doubtless in many places margined by an ice-foot. It was during this epoch that the highest river-terraces began to be formed, the rivers ploughing their way down through the glacial and fluvio-glacial and interglacial accumulations of earlier ages.

Starting from the horizon of the 100-ft. beaches and estuarine deposits we have little difficulty in tracing the broader features of the succeeding geographical changes. It will be remembered that in the basin of the Tay, immediately overlying the deposits referred to, sands and gravels of fluviatile origin are encountered. The presence of these shows that the sea eventually retreated, and so allowed streams and rivers to cut their way down through the thick sheets of clay, sand, and gravel which had gathered over the floor of the old estuary. The river-deposits further tell us that the land must by-and-by have attained a higher level than it does now, for they here and there pass below the present beds of the rivers. When the sea first retreated, the old fluvio-glacial and estuarine beds extended as a broad

plain over the lower reaches of the valleys of the Earn and Tay. Through this plain the rivers eventually cut their way to a depth of more than 100 ft., and gradually removed all its materials over a course which can hardly be less than two miles in breadth below Bridge of Earn, and is considerably more than that in the Carse of Gowrie. This erosion naturally implies a considerable lapse of time, during which the climate must have been gradually becoming better; for, resting immediately upon the old alluvia of the Tay and Earn, we come upon the peat-bed with its abundant temperate flora.

The occurrence of this particular peat-bed at and below low water, and the similar appearance of peat with buried timber of large size occupying a like position at many places round the Scottish coasts, sufficiently indicate the fact that after the disappearance of glacial conditions the sea retreated, and the land extended farther than is now the case. As all the plants hitherto observed in these old peat-beds are still indigenous to Scotland, it may be inferred that the climate could not have been less genial than it is to-day. The probabilities are that it was even more genial; but since this is a conclusion which is only arrived at after a review of all the evidence furnished by the buried forests and submerged peat of the British Islands and the opposite coasts of the Continent, we shall leave it to be discussed along with other matters in the sequel.

Confining our attention to the evidence relating to Scotland alone, we find that the retreat of the sea which marked the era immediately succeeding the formation of the estuarine flats and beaches of the 100 to 130-ft. level continued during the subsequent growth of the great forests. Before these forests had taken possession of the valleys the ancient rivers had ploughed out and removed vast quantities of materials of glacial, fluvio-glacial, and marine origin; and their alluvial plains formed extensive flats overlooked on one or both sides by the bluffs of the old 100-ft. terrace. All those wide plains became in time densely wooded—while thick growths of reed-like plants shot up upon the low alluvial banks of the rivers. Forests of oak and other trees covered the Lowlands and extended far into the heart of the

Highlands and Uplands—rising to elevations on the mountain-slopes where neither oak nor pine will now flourish. As the Inner and Outer Hebrides and the Orkney and Shetland Islands were similarly well-wooded, we might suspect that those regions were at this time united to the mainland—a conclusion which, as we shall afterwards see, is supported by other evidence. Clad with thick forests and supporting an abundant mammalian fauna, Scotland might well have been inhabited by man at that time. The only evidence of his presence, however, is the dug-out canoe obtained from the bottom of the Carse-deposits at Perth. All that we can infer from this is that he lived in the land before the bulk of the Carse-clays had been deposited. The position in which the canoe occurs, however, leads to the inference that the climax of the forest-epoch had passed and resubmergence had ensued before the old boatman lost his craft in the ancient Tay.

The next stage in our history is represented by the Carse-clays and sea-beaches of the 45 to 50-ft. level and by the peat which overlies the buried timber of our deeper bogs. In these accumulations we read the evidence of changed geographical and climatic conditions. The immense quantities of drift-peat and timber which occur underneath and in the lower portions of the Carse-deposits tell of a time of active forest-clearing. We can picture to ourselves the beginning of the period when the sea was slowly gaining on the land. The rivers, which during the epoch of forest-growth were probably of no greater size than they are to-day, now acquired a larger volume, and commenced to overflow the low-lying tree-covered plains. Sheets of gravel and sand, and alluvial silt and mud, were thus gradually spread over the site of the ancient forests; while in many places all relics of the old land-surface were swept away. The torrential character which the rivers assumed at this time is shown by the masses of coarse shingle which they carried along. The trees that grew close to the water were often undermined, and, falling into the streams, were floated down the valleys. Ere long, however, the lower reaches of the lowland valleys were converted into broad estuaries, and the destruction of the forest-bed in those regions was arrested. The muddy rivers con-

inued to flow with undiminished volume, but the coarser ediment they swept along came to rest soon after it entered he estuarine waters—only the finer silt and mud being carried urther, and distributed over the whole wide surface of the rowned low grounds. For a long time, however, much drift-'ood continued to find its way out to sea, and becoming water-›gged sank to the bottom, where it was eventually buried. Ian, as we have seen, lived along the shores of our estuaries t this time.

The fauna of the Carse-deposits and raised-beaches closely esembles that of the present time; although it is quite con-istent with colder waters than now lave our shores. On he other hand, there are some indications of even more ;enial conditions than now obtain. Thus, on the borders ›f the Firth of Clyde a certain beach-deposit occurs to vhich the late Dr. Crosskey has drawn special attention. It contains such shells as *Psammobia ferroensis* and *Tellina ncarnata* (*tenuis*?), of larger size and in greater numbers han they at present occur, living in the neighbouring seas'— fact indicating, he thought, conditions of climate possibly more genial than those which exist at the present day. Similar facts are recorded in connection with certain raised-beaches in Norway, and their significance will be discussed later on. It is enough at present to suggest that the large shells in question may represent the fauna that flourished in our seas during the genial forest-epoch. When submergence ensued, some time would elapse before the temperature of the sea became much affected—especially on the west coast of Scotland; and the conditions may have been sufficiently favourable, therefore, in the earlier stages of depression.

Although the fauna of the raised-beaches, &c., is certainly not arctic, but suggestive rather of temperate or cold temperate conditions, yet the physical evidence seems to indicate colder conditions than now exist. Not much weight can be attached to the occasional occurrence of isolated stones and larger erratics—even if it be admitted that all these were dropped from floating ice; for now and again in our own days ground-ice carries down many small erratics to our estuaries. But the general character of the Carse-clays themselves seems often to suggest the glacial origin of their materials.

The fine tenacious brick-clays, and even the less cohesive silty or loamy clays, cannot be likened to the dark sludge and mud which now gather in our estuaries. They in some measure resemble the laminated clays of the 100-ft. terrace. The rivers that flowed into our estuaries while the Carse-deposits were being accumulated must have been abundantly charged with the 'flour of rocks' and finely levigated material. Whatever the conditions may have been in the earlier stages of submergence, the climate certainly must have become cold and ungenial as the depression continued. For, as we have seen, before the submergence had reached its maximum, glaciers had again appeared in our mountain-regions; and in the Western Highlands they eventually descended to the sea and dropped their moraines on the beach-deposits then forming. That many of our mountain-valleys contained glaciers at this time cannot be doubted; but, had it not been for the fortunate circumstance that some of these glaciers reached the sea and deposited their moraines on the beaches of the period, we should probably have assigned all the valley-moraines to the closing stages of our epoch of district ice-sheets. We should, in short, have considered these later moraines to have been dropped during the final retreat of the valley-glaciers of the earlier epoch. But the intercalation of the beach-deposits shows clearly that we are dealing with the detritus of a later and less important glaciation. The glaciation referred to, however, was only relatively unimportant. In point of fact, as I have shown,[1] the snow-line at the epoch in question had an average elevation of only 2,500 ft., so that each considerable group of mountains nourished glaciers some of which descended into the great glens.

Scotland, submerged to the extent of 45 to 50 ft.—with its mountains snow-clad and nourishing considerable glaciers —was no longer so well covered with forests as in the preceding genial stage. The climate had deteriorated—had become colder and probably more humid. These changed conditions would tell at an early stage on the forests, which would begin to decay in the maritime regions and at the higher elevations of the land. But the conditions that were adverse to them

[1] See Chap. XIX. p. 252.

favoured the growth and spread of the bog-moss and its numerous allies.[1] And thus we can readily picture to ourselves the gradual destruction of the woodlands and their entombment under growing peat. To what extent Scotland was cleared of trees it is, of course, impossible to tell. But when the geographical position of that country and the conditions of the epoch under review are fully considered, we shall probably not greatly err if we compare Scotland at the time in question to Northern Norway in our own day.

Ere long another geographical change supervened, and the land again gained on the sea, until the latter had retreated considerably beyond its present limits. The climate at the same time became more genial, and favourable to the growth of forests. Oak, pine, and other trees once more overspread the land—invading the tracts which had formed the moorland wastes and peat-bogs of the preceding cold and humid epoch. The conditions, in short, seem to have closely resembled those that obtained during the earlier stage of great forests. By-and-by, however, another oscillation of the sea-level took place—the land was again partially submerged, forest-decay recommenced, and peat-bogs once more flourished vigorously. To this epoch of more humid and colder conditions we assign the later raised-beaches of our coast-lands. It is significant that in our loftier mountain-regions we meet with a high-level series of terminal moraines and rock-basins, which indicate a snow-line at 3,500 ft. We cannot directly connect that final epoch of small glaciers with the last submergence of our coast-lands. No moraines come down to the level of the 25 to 30-ft. beaches. Yet I have little hesitation in concluding

[1] It is, perhaps, hardly necessary to insist upon this point; botanists will admit that for the growth and increase of bogs wet conditions are necessary. In dry regions no bogs occur. Thus A. von Krassnoff says he could find no trace of peat or peat-formers anywhere in the Thianschan (*Verh. Ges. für Erdkunde, Berlin*, Bd. xv. p. 266). There is a similar absence of peat and peat-forming plants in Western Siberia. In our own islands the distribution of peat shows that this formation is dependent on the rainfall. Thus, bogs are more numerous and in a more flourishing condition along the Atlantic seaboard than in inland districts. I have noticed, indeed, that peat usually attains a greater thickness upon mountain-slopes that face the direction of 'rainy winds' than on the opposite or lee-side of the same hills. The wetter the climate, as Professor Blytt has remarked, the more widely-spread are the peat-forming plants. In Bohemia, for example, the thickness of the peat of that region is in direct proportion to the annual rainfall—it is thickest where the precipitation is greatest. (See Dr. Fr. Sitenský, 'Ueber die Torfmoore Böhmens,' &c., *Arch. d. naturwiss. Landesdurchforsch. v. Böhmen*, Bd. vi. Nr. 1, p. 56.)

that the formation of our most elevated rock-basins and moraines coincided with the submergence in question.

Lastly the sea retreated to its present level, and with this latest change the climate would appear to have become somewhat drier; for there is abundant evidence to show that nowadays the rate of growth of peat is exceeded by that of decay. How much of this decay is the result of natural causes, and to what extent it may be due to the action of man, is hard to say. It is certain, however, that the destruction of the earlier forests—the remains of which occur under the Carse-clays and at the bottoms of our oldest peat-bogs—cannot be assigned to man's hand. Nor can we attribute to human agency the later growth of peat under which the old forest-lands became buried. Neither can the subsequent recrudescence of forest-growth which preceded the last partial depression of the land be due to any other than natural causes. The two forest-beds, in short, indicate epochs of drier or continental climatic conditions, separated by an intervening epoch of more humid or insular conditions. It is only reasonable, therefore, to infer that the decay and overthrow of the second crop of great forests, and the growth of the peat underneath which they now lie buried, may in like manner be the result of climatic vicissitudes. It is obvious, however, that man has played no unimportant part in the work of destruction.

It has been surmised by some writers that much of the old timber may have been blown down, and they have referred to the fact that all the trees in some peat-mosses often lie in one direction, as if they had met their fate at one and the same time.[1] The woods, as we know, grew thick and close; the trunks rose tall and straight, and their roots were fewer and not so widely spreading as they would have been had the trees grown in isolated positions. Hence, when a breach was once effected by the overthrow of the sturdier trunks that guarded the outskirts of the forest, the destruction of the less firmly-rooted timber, it has been thought, would

[1] *Highland Society's Prize Essays*, vol. ii. p. 19 (Old Series); Rennie's *Essays on Peat-moss*, p. 31; Sinclair's *Stat. Acc.*, vols. iv. p. 214; v. p. 13[illegible]; and xv. p. 484; *New Stat. Acc. Paisley* and *Carluke*. *Vide* also, for similar phenomena in English and foreign peat-mosses, *Phil. Trans.*, vol. xxii. p. 980; Rennie's *Essays*; Degner, *De Turfis*, p. 81.

speedily follow. Doubtless many acres may have been desolated in this way. But it seems extravagant to infer that all the buried timber met its fate after this fashion. We cannot suppose the peculiar position of the trees to be in every instance the result of violent storms. Trees are usually bent over in some particular direction by prevailing winds, and when any cause leads to their overthrow, whether it be natural decay or otherwise, they naturally fall as they lean.

Other causes of destruction have been suggested, such as lightning, and what are known in North America as ice-storms. Neither of these causes can be quite ignored, yet they can hardly have been other than partial in their operation.

But when we come to ask what share man has had in the work, we find that he has been a far more potent agent of destruction than any of the causes yet referred to. Besides the evidence of his hand afforded by the charred wood under peat, we sometimes come upon marks of adze and hatchet.

The earliest historical accounts of North Britain have afforded abundant food for controversy to archæologists, but when the geologist has gleaned together the few descriptive remarks which occur here and there, in the pages of Tacitus, Dion Cassius, Herodian, and others, he will find that his knowledge of the physical aspect of Scotland does not amount to much that is very definite. He will learn, however, that Caledonia was notorious on account of its impenetrable forests and impassable morasses. But the precise extent of ground covered by these woods and marshes must always be matter of conjecture. The forest-land known as *Sylva Caledoniæ* appears to have stretched north of the wall of Severus, but south of that boundary large forests must have existed; indeed, down to much more recent times, many wide districts of southern Scotland could still boast of their woodlands. Of the nature of those waste plains, described by the ancients as full of pools and marshes, we can have little doubt, although we cannot of course pretend to point out their particular site. Those who have traversed the central counties of Scotland must have been struck with the numberless sheets of alluvium which everywhere meet the eye, betokening the presence, in former days, of so many lakelets. In

Bleau's Atlas, many lochans appear in spots that have long ago come under the dominion of the plough. These, however, must form but a small proportion of the lakes which have been drained since the time of the Romans. Such inconsiderable peaty lochans were not likely to merit particular mention by those who had gazed on the Alpine lakes, save as they became vexatious interruptions to their progress through the country, and surrounded, as many of them in all probability were, with treacherous morasses, the words of the old historians appear to have been descriptive enough of certain ample areas in the Scottish Lowlands.

It seems to have been the common practice of the Romans to cut down the trees for some distance on either side a 'way,' to prevent surprise by the enemy. Several old 'ways' have been discovered on the clearing away of peat-bogs, and in their neighbourhood lie many trunks of trees, bearing evidence of having fallen by the hand of man. The presence of Roman axes and coins leaves us in no doubt as to who the destroyers were. But it is quite evident that such embedded relics do not enable us to fix the age of a peat-bog. They merely tell us that the origin of the peat cannot date back beyond a certain period, but may be ascribed to any subsequent time. Hence it is impossible to say what amount of waste we are to set down to the credit of the Romans. Some authors have, perhaps, been too ready to exaggerate the damage done by the legions. The buried forests which can be proved to have fallen before Roman axe and firebrand are not many after all; but we may reasonably suppose that these form only a portion of the woods which were cleared at that time.

We have, however, what appears to be direct evidence to show that some regions had been divested of their growing timber before the Roman period; for, if Solinus may be trusted, the Orkneys were, in the days of the Romans, bare and bleak as they have been ever since. He says 'They are three in number, and contain neither inhabitants nor woods; here and there they bristle with shaggy copse and herbs, but, for the most part, all they show is bare sand and rock.' A patriotic Orcadian might insist that the statement 'three in number' renders what follows untrustworthy; and perhaps

might prefer the testimony of Ossian, who, in his poem of 'arric-thura,' says of some island in the group, 'a rock nds along the coast with all its echoing wood.' According Torfaeus (historiographer to the King of Denmark),[1] the ndition of the Orkneys in the year 890 agreed with e description given by Solinus.[2] For at that time nar conferred a great boon upon his countrymen by ching them the use of peat for fuel—there being then, Torfaeus says, no woods in the islands. Yet it is well own that the peat-bogs of the Orkneys, and even those the Shetlands, contain the remains of considerable trees.

My limits will not permit me to consider in detail counts of the condition of the Scottish forests in times bsequent to the Roman period. Any reference by the roniclers to the state of the woodlands is only incidental, l perhaps not always to be relied upon. It is interesting, wever, to learn from Boethius that the *horrida Sylva ledoniæ* had in his time become mere matter of history.[3] e further tells us that Fifeshire had formerly been well oded (in the times of some of his early Scottish kings); t 'it is now,' says his old translator, 'bair of woddis; for e thevis were sometime sa frequent in the samin that they icht na way be dantit, quhill the woddis war bet down.'[4] gain Boethius describes the island of Isla (the peat-bogs which contain roots and trunks of trees) to be an island :h in metals which could not be wrought on account of e want of wood.[5]

After the period to which Boece refers, any allusions to e aspect of the country are best sought for in cartularies d such records. For the rights acquired by monasteries er various forests throughout the country, these cartularies 'ord abundant evidence. Chalmers [6] has enumerated many

[1] Torfaeus wrote about 1690. He was a native of Iceland, and died in l9.

[2] Solinus is supposed to have written about A.D. 240.

[3] If this had not been the case, he would surely have quoted a less ancient hority than Ptolemy for the site of the ancient forest. See *Cosmographie d Description of Albion*.

[4] *Croniklis of Scotland*, chap. xi.

[5] Bellenden's version of the passage is as follows: Isla is 'full of metallis, thair wer ony crafty and industrius peple to win the samin;' but he drops allusion to the want of wood in the island.

[6] *Caledonia*, vol. i. p. 792, &c.

instances of special grants by kings and barons 'of particular forests in pasturage and panage, and for cutting wood for building, burning, and all other purposes;' and Mr. Tytler[1] has added to the list. It need hardly be remarked that the greater part of these woodlands has long disappeared. And yet the old cartularies 'abound with notices of forests in every shire during the Scoto-Saxon period.' I have not hesitated to quote the authority of those records, and the opinions of two such learned and correct writers as Chalmers and Tytler. No one can deny that the evidence of the cartularies is in favour of a better wooded condition for the country than now obtains. But we must guard against the mistake of supposing that all the area embraced under the designation of a 'forest' was covered with forest-trees. And there can be little doubt that both Chalmers and Tytler read the cartularies in the light of the facts which are disclosed by the peat-bogs. The trunks of pine, oak, ash, and other hard timber dug out of the bogs, were regarded as proofs that the regions indicated by the cartularies were in reality the sites of great forests at the time to which those records refer. But it is probable, nay in many cases quite certain, that much of this buried timber belongs to a more remote period. But even with this reservation, Scotland, down to the fourteenth century, would appear hardly to have merited the description given by Æneas Silvius at a later date. During the civil commotions of the country,[2] and the long wars with England,[3] much wood seems to have been destroyed, and the gradual progress of cultivation also began to encroach upon the forest-lands. The great number of salt-pans that were early established in Scotland, and the right which the proprietors usually obtained to cut the requisite firewood from the forests of the country, was another cause of destruction, and much timber disappeared in this way from the maritime districts. But although wood

[1] *Hist. of Scot.*, vol. ii. chap. ii. third edit., and the authorities there quoted and referred to.

[2] Fordun relates that Robert the Bruce defeated the Earl of Buchan near Inverury, and ravaged the district with fire. The marks of fire are said to be visible on the trees in the peat-bogs of that neighbourhood. Sinclair's *Statistical Account*, vol. xx. p. 144.

[3] Knighton mentions that in the reign of Richard II., the English, under the Duke of Lancaster, besides firing the forests, employed eighty thousand hatchets in the work of their destruction.

appears to have been the fuel commonly employed in the manufacture of salt, yet it is not unlikely that peat may also have been burned in some cases. It is certain, at least, that peat was a common enough fuel in David I.'s reign, and that[1] 'petaries became frequent objects of grant to the abbots and convents during the Scoto-Saxon period.' This fact ought perhaps to be looked upon as a farther proof of the increasing decay of the forests.

But by far the most remarkable testimony to the bare condition of the country is furnished by the Acts of the Scottish Parliament. From the times of the first James, stringent acts were adopted by successive Parliaments,[2] having for their object the preservation of the woods. Æneas Silvius (afterwards Pope Pius II.), who visited this country about the middle of the fifteenth century, relates: 'We have seen the poor people almost naked, who came to beg at the doors of the temples, receive for alms pieces of a stone, with which they went away contented. This kind of stone, being impregnated either with sulphur or some other combustible material, they burn instead of wood, of which their country is destitute.'[3] Such a statement regarding the bare condition of the country might have been thought somewhat exaggerated, for it is the testimony of a visitor from more favoured climates; but its truth is curiously illustrated by an Act of the Scottish Parliament, passed in the reign of James IV.—'Anent the artikle of greenewood, because that the Wood of Scotland *is utterly destroyed*, the unlaw theirof beand sa little: Therefore, &c.'[4]

There are, of course, numerous traditions regarding the

[1] *Caledonia*, vol. i. p. 793.

[2] See *Acts of Scottish Parliament*. The more interesting acts referring to the state of the woods were passed as follows:—James I., Second Parliament, A.D. 1424; James II., Fourteenth Parliament, A.D. 1457; James IV., Sext Parliament, A.D. 1503; James V., Fourth Parliament, A.D. 1535; Mary, Sext Parliament, 1555; James VI., First Parliament, 1567, Sixth Parliament, 1579, Eleventh Parliament, 1587. It is curious to notice how, from the time of James I., the penalties imposed upon the destroyers of wood increase in severity. Pecuniary fines are succeeded in time by stocks, prison, or irons; the culprit is to be fed on bread and water during confinement, and to be scourged before parting from his jailers. The climax is reached in the following act, which became law in 1587:—'Whatsoever persone or persones wilfully destroyis and cuttis growand trees and cornes, sall be called therefore before the Justice or his deputes, at Justice Airs, or particular diettes, and punished therefore to the death, as thieves.'

[3] *De Europa*, cap. 46.

[4] Sext Parliament, A.D. 1503.

former wooded condition of various districts from which the trees have long since been stripped. Many of these refer to some of those woods which I have already mentioned, as being frequently named in the cartularies and similar records.

Another line of evidence is supplied by local names; but into this subject I cannot enter here.

The short outline of historical facts now given seems to prove:—

1st. That when the Romans entered Britain they found the surface of the country to some extent covered with forests, but diversified in many places with bogs and marshes.

2nd. That to this period we must refer the destruction of some portions of the ancient forests, whose remains are dug out of the peat-mosses; but what amount of damage the woods then sustained we have no means of ascertaining.

3rd. That from the time which elapsed after the departure of the Romans down to the eleventh century we have no certain records referring to the state of preservation of any part of the Scottish woods, unless we except the statement of Boethius, who tells us that Fife had in a great measure been divested of its forests by some of the early Scottish kings.

4th. That from the eleventh to the thirteenth century, and down even to later times, there appear to have been still considerable areas of forest-land, the rights to which were frequently granted to ecclesiastical communities and others.

5th. That during these centuries much forest was thus cleared and brought under cultivation; that at the same time woods were exhausted by building and burning, more especially as fuel for the salt-works; while extensive tracts were laid waste during times of war and civil strife.

6th. That from the time of James I. there appears to have been a progressive decay of the remainder of the Scottish woods.

There can be no doubt, then, that man must be credited with no small share in the work of destruction. It may be questioned, however, whether he was, after all, the chief agent. Certain considerations would seem to show that too much has been reckoned up against him.

We have seen that the general character and distribution of much of the timber in our peat-bogs point to the former prevalence of dry continental conditions. Now, when the climate became insular, it is almost needless to say that this change would affect vegetation. The trees in what are now the maritime districts, would soon succumb to the influence of the sea-air. Thus, wide areas along the coasts, and in the islands of Orkney, Shetland, and the Hebrides, would be displenished. The trees, falling to the ground, would obstruct the surface-drainage, and thus give rise to marshes in which the bog-mosses would speedily multiply, until, by-and-by, they overwhelmed the prostrate timber, and covered the whole with a mantle of growing peat. Nor can it be doubted, that, on the moist hill-tops, and in many places in the interior of the country, similar changes would come about.

It is a mistake, however, to suppose that peat always overlies a prostrate forest. There are cases where no trace of wood can be detected. Peat of this description is not uncommon in the upland districts of the south of Scotland, where it frequently clothes the tops and slopes of considerable hills to a depth of from six to twelve, and even sixteen feet. Here, then, there are no trees to account for its presence. Again, in the peat of the higher hill-tops, when trees do occur, they are of small size—mere brushwood, in fact, the overthrow of which, we can hardly think, would have done much in the way of collecting moisture for the support of the bog-mosses.

From a consideration of these and other points, it seems not unreasonable to suppose that the decay of the woods and the growth of the peat were both alike to some extent induced by a change of climate. The partial submergence which took place after dry continental conditions had for some time prevailed, would render the country less capable of supporting an exuberant forest-growth, and would at the same time increase the moisture of the atmosphere, and thus favour the spreading of the bog-moss and its allies.

As the beginning of these changes carries us back far beyond the dawn of authentic history, it follows that much of

the peat and buried timber of our country may be of great antiquity. And, indeed, in the case of many bogs, we seem more likely to err in ascribing too recent than too early a date to the period of their formation. We cannot estimate the time which has gone by since the Western Islands supported those timber-trees, the remains of which are dug out of the peat. It is highly probable, that, at the period in question, those islands were joined with the mainland, and shared a continental climate. To the same date we may refer much of the buried timber of the Orkney and Shetland Islands. Again, the more elevated peat-bogs of the country must have been among the first to be formed; for any change from a continental to an insular state would tell first upon the trees that grew along the sea-board, and at the higher elevations of the land. It seems reasonable, therefore, to conclude that, long before the Romans set foot in Britain, the overthrow of timber and the growth of peat-bogs had made considerable progress; that, in short, the Caledonian Wood was but the relics of that great forest which in former ages had spread over all Scotland and the bed of the adjacent sea.

Farming operations have encroached, and every year are continuing to encroach, upon the moss-lands. But a very long time indeed will elapse before the great 'flow-mosses' or quaking bogs, some of which exceed forty feet in depth, shall be improved out of existence. Draining, however, has done much to stop the growth of peat in many places, and is destined to do still more. I feel sure, from what I have myself seen, that the general decay of the peat-bogs (I refer more especially to the peat on flat hill-tops and sloping ground) far exceeds the rate of growth. Frost and rain are breaking down the peat and washing it rapidly away, and in many cases only a few shreds have been left scattered here and there over the tops and slopes of the hills. Under present climatic conditions, the eventual clearing of all these high grounds is only a question of time. This change must, no doubt, be attributed, in large measure, to improved systems of drainage, but it seems not improbable that it may also in some degree be due to a lessened rainfall—the bogs not receiving so much moisture as they did in former times.

But, for obvious reasons, this would be a very difficult matter to prove.[1]

So many points of evidence have now been adduced, that it will be well, before we address ourselves to the study of the glacial deposits in other countries, to reckon up here in a few paragraphs what appears to have been the general succession of geological changes in Scotland from the advent of the Ice Age down to recent times.

1. The Lower Till or Boulder-clay is the bottom-moraine of a great *mer de glace* which covered all Scotland up to a height of at least 3,500 feet, so that only the tips of the highest mountains peered above the surface of the ice-sheet. The Scottish ice was confluent on the bed of the North Sea with the inland ice of Scandinavia. The Orkney and Shetland Islands were overflowed by these united masses. The Outer Hebrides were likewise traversed by ice coming from the mainland—the *mer de glace* terminating in a great wall of ice in the deep waters of the Atlantic.

2. The Lower Till is separated in many places by intercalated freshwater and marine deposits, from an overlying upper boulder-clay. These deposits give evidence to show that the great *mer de glace* eventually melted away, exposing a wide land-surface, which in time became clothed with a temperate flora and occupied by a temperate fauna. The climate thus gradually changed from arctic to temperate. Submergence next ensued—the climate at the same time passing from temperate to arctic. The maximum amount of submergence is unknown, but seems not to have exceeded 500 ft. or thereabout.

3. The Upper Boulder-clay or Till immediately overlies the interglacial beds referred to in the preceding paragraph. It is the ground-moraine of another general *mer de glace*,

[1] For general information on Scottish peat-mosses consult Rennie's *Essays on Peat*; Aiton's *Treatise on the Origin, Qualities, and Cultivation of Moss-earth*; and Steel's *History of Peat-moss*. Dr. Anderson's *Practical Treatise on Peat* is a whimsical attempt to prove that peat-moss is a plant *sui generis*! [The account of the Scottish peat-mosses given above is condensed from a paper by the author communicated to the Edinburgh Royal Society (*Trans.*, vol. xxiv. p. 363, 1866). Professor Blytt of Christiania subsequently came to similar conclusions from an examination of the flora and the peat-bogs of Norway. See chap. xxxi.; also *Prehistoric Europe*, chaps. xvi.–xxi., in which the post-glacial deposits are discussed in detail.]

which seems to have been somewhat less extensive than its predecessor.

4. The Kames and Åsar and many large erratics and perched blocks belong to the period of dissolution of this second *mer de glace*. To the same epoch pertain many lacustrine terraces at high levels (= glacial lakes) occurring especially in the Southern Uplands.

5. After the retreat of that lesser *mer de glace* milder conditions of climate appear to have prevailed for a prolonged time. Some of the older alluvia of the Lowlands may pertain to this stage. (This inference is confirmed by the evidence derived from the contemporaneous deposits of the Continent. Indeed, were it not for that evidence, we should hardly be able to say that a prolonged interglacial interval separated the epoch of our 'second' general *mer de glace* from that of our district ice-sheets and great valley-glaciers (6). All that we could assert would be that after the general *mer de glace* had retreated from the Lowlands and become resolved, as it were, into a series of small local glaciers, a great recrudescence of glacial activity supervened, so that much of the ground vacated by the ice-sheet was re-occupied).

6. The Ground-Moraines and large Terminal Moraines of the mountain districts are the products of our 'third' epoch of glaciation.[1] They indicate the existence of considerable district ice-sheets and great valley-glaciers which in places became confluent on the low grounds. Icebergs at this time were calved by the glaciers that occupied our sea-lochs. These conditions were preceded and accompanied by submergence of the land for more than 100 ft. (=Marine Clays, &c. with arctic and boreal fauna). Much floating-ice distributed erratics over the drowned areas. To this epoch belong the glacial lakes of Lochaber, and the high-level

[1] I have spoken of 'first,' 'second,' and 'third' glacial epochs, but it must not be inferred that the so-called 'first glacial epoch' was actually the earliest of the series. In Scotland there is no recognisable trace of any earlier stage of glaciation than that which for convenience' sake I have designated the 'first.' But, as we shall see presently, there is evidence in England to show that the epoch of maximum glaciation in our islands was not the earliest cold stage of the Glacial Period. And still stronger evidence is furnished by Continental geologists to prove that an earlier stage of glaciation (followed by interglacial conditions) obtained in Europe before the advent of the greatest of the *mers de glace*.

gravel-terraces of our larger river-valleys. The arctic plant-beds also in all probability pertain to the same general horizon.

7. The preceding epoch of partial submergence was followed by re-elevation of the land or retreat of the sea, and a gradual amelioration of climate. Eventually great forests covered the country, and a temperate mammalian fauna roamed over Scotland. Our western and northern islands were probably united to the mainland, which extended far out into regions that are now under water (=Lower Buried Forest).

8. The next change is indicated by the Estuarine Deposits of our larger river-basins and the Raised Beaches, at 45 to 50 ft. or so above the present sea-level. These are in places covered by the Terminal Moraines of valley-glaciers. The genial climate of the epoch of great forests was, in short, followed by colder and more humid conditions, which greatly favoured the growth of Peat. (Peat overlying the lower buried forest; high-level River-Terraces.)

9. The sea again retreated and Scotland attained a wider extent, but whether this gain of land was equal to that which occurred during the growth of the lower buried forest we cannot tell. With re-elevation of the land the climate became drier or more continental, and a second vigorous forest-growth took place (=Upper Buried Forest).

10. Submergence now once more ensued, to the extent, in central Scotland, of 25 or 30 ft.; and the climate at the same time became colder and more humid, local glaciers appearing in our loftiest mountain-areas. The conditions, while adverse to the growth of forests, were favourable to the extension of peat-bogs, underneath which wide areas, cleared of their trees, were eventually buried. (Peat overlying the upper buried forest; raised beaches of 25 to 30-ft. level.

11. Finally, the sea retreated and the present conditions supervened. The climate would appear to be drier now than during the preceding epoch of limited submergence.

CHAPTER XXIV.

GLACIAL PHENOMENA OF ENGLAND.

Necessity of comparing deposits of different countries—Glacial succession in the low grounds of eastern England—The Pliocene and Pleistocene of Norfolk—Conditions of deposition of the Pliocene—Arctic character of the Weybourn Crag—The Forest-bed indicates genial climatic conditions—Arctic fresh-water bed—The glacial accumulations at Cromer—Mr. Reid's views as to the origin of the 'contorted drift.'

NO one who shall endeavour to trace the origin and history of the glacial accumulations within any particular area need hope to do so satisfactorily without continual reference to the superficial phenomena of contiguous regions. Individual sections, however clear and apparently consecutive they may be, yet do not contain all the truth; and it would be extravagant to suppose that the deposits of any limited locality tell one everything that he might hope to learn of the physical history of the Ice Age. Two observers who should restrict their examinations, the one to a mountainous district, the other to low-lying tracts at a distance from the hills, would be sure to form very different ideas of the Glacial Period. One might be all for glaciers—the other all for icebergs. The earlier students of the Scottish glacial deposits held that the whole island had been swept from north-west to south-east by an ice-laden ocean-current, and they pointed triumphantly to the direction followed by the rock-striations and the till of the central Lowlands as conclusive proof of their theory. But had they been as well acquainted with the Southern Uplands and the Northern Highlands as they were with the low grounds of the Lothians, this iceberg theory would probably never have been advanced. It is only when the geologist has gone over a sufficiently large tract of country and studied its superficial accumulations at all levels, in lowlands and mountains alike, that he can safely generalise. He will not, however,

fully appreciate the results obtained if he venture to ignore what other workers are doing elsewhere in the same field of inquiry. When he compares his own conclusions with those of others, he will often find reason to hesitate and proceed with caution where, previously, he may not have perceived any difficulty. On the other hand, he will not infrequently have his own inferences strengthened, and here and there catch a hint that may enable him to see newer and deeper meanings in his facts than he had any idea of before. Certain it is that we shall never acquire a proper knowledge of the physical changes that supervened during the Glacial Period until the records of that age have all been correlated and compared. But what a vast amount of work remains to be done before this can be adequately accomplished! Nevertheless, some approximation towards it can be, or ought to be, indeed, attempted. A great deal has already been learned. The general succession of events that marked the progress of the Ice Age in widely separated countries has been more or less clearly made out, and it becomes, therefore, a matter of importance to inquire how far the conclusions so arrived at harmonise. If they shall be found to tally as closely as could have been expected, we shall have so far a guarantee of their accuracy. In this and succeeding chapters, then, I shall attempt, with what success I may, to compare the results obtained in Scotland with the conclusions arrived at by English, Irish, and foreign geologists.

So long as the observer confines his attention to the mountainous districts of England, he will experience no difficulty in detecting the traces of former extensive glacial action. He will find, both in Wales and the Lake district, that the mountains frequently show that peculiar flowing and rounded contour which is so characteristic a feature of ground over which land-ice has passed. In the valleys he will see polished and striated surfaces of rock, and heaps of morainic deposits; and the presence of numerous true rock-basins will further conspire to assure him that the influences under which Scotland assumed much of its most characteristic scenery have also had no small share in designing, or at all events in adding some of the latest and finest

touches to, that beautiful picture of hill and dale and lake that so charms one in Cumbria and Wales.

But when we leave the hilly districts and begin to traverse the broadly undulating low grounds, the evidences of old ice-action often become obscure and hard to read. And our difficulties increase the farther we recede from the mountains. The tough and firm rocks of Cumbria and Wales are replaced as we travel outwards from these centres by rocks less capable of retaining any ice-markings which may at one time have been graven upon them. Add to this the great thickness of superficial materials, underneath which the strata in the low grounds are frequently buried, and the confused and intricate appearance often presented by these accumulations, and it will be admitted that the geologist who sets for himself the task of unravelling the evidence, so as to educe a clear and consecutive story, has no easy work to accomplish. Not the least perplexing part of his task will consist in attempting to discover the meaning of the terminology employed by different observers. Similar deposits he will find are known under different names; while under one and the same designation accumulations are described which are certainly not the same, but in some cases as wide apart as they could well be.

As already indicated, the glacial accumulations which are now to come under our attention show a very different development according as they appear in upland or in lowland tracts. I purpose, therefore, to treat first of the deposits that cloak the lower-lying districts of England—amongst which we encounter the oldest members of the glacial series. It is impossible to go into much detail, and I must therefore content myself by tracing what seem to me to be the more important features of the evidence—those, namely, which enable us to ascertain the general succession of the beds. We shall, in short, confine our attention chiefly to those facts which are of general interest as indicating the leading geographical and climatic changes of the Glacial Period.

Turning first to the low-lying districts of eastern England, we find that those regions are more or less thickly mantled with superficial accumulations which along the coast-line

are often exposed in fine sections. One of the most interesting localities for the study of these deposits are the cliffs of Norfolk, at and near Cromer. These sections have long been famous, and must ever be looked upon with interest, inasmuch as we obtain from them the only reliable evidence as to the kind of plants and animals that clothed and peopled England before the epoch of maximum glaciation. The earliest notice we have of the Cromer beds is in a paper by Mr. R. C. Taylor (1827), since which time they have formed the subject of an extensive geological literature.[1] Before considering the history of the glacial deposits, however, it will be well to pass in review the character and origin of the beds which immediately underlie them. These consist of certain fresh-water and estuarine deposits, with subjacent marine accumulations, which together form the upper members of the British Pliocene system. The series as represented in the east of England shows the following succession :—

7. *Leda myalis* bed.
6. Forest-bed series.
5. Weybourn Crag.
4. Chillesford Crag.
3. Norwich Crag or Fluvio-marine series.
2. Red Crag.
1. Coralline or White Crag, and Lenham beds.

It has long been known that the marine molluscan fauna of these Crag-beds tells a tale of gradually changing climatic conditions. In the oldest member of the system—the Coralline Crag—the general facies of the fauna clearly indicates a warm-temperate climate, for all the living species are southern forms. In the Red Crag, however, northern forms begin to appear, and increase in numbers as we pass upwards to the higher members, while at the same time the extinct and southern forms gradually die out. Thus when we reach the Chillesford and Weybourn Crags, we find the marine molluscan fauna presenting a thoroughly arctic aspect. Immediately above the marine Weybourn Crag come the fresh-water and estuarine beds known as the Forest-

[1] The reader will find lists of all the papers, &c., dealing with this district in Mr. Clement Reid's admirable description of the geology of the country around Cromer, *Mem. Geol. Survey*, 1880. See also paper by the same author, *Geol. Mag.* 1880, p. 55.

bed series. It is beyond my purpose to give any detailed description of this series further than to say that geologists are agreed that the beds are essentially of fluviatile origin. They consist of an upper and a lower fresh-water bed, separated by intervening estuarine beds, which are often crowded with drift-wood and the stumps and roots of trees. These last were formerly supposed to occupy the place of growth, and to indicate an old land-surface; hence the name given to the series. It has now been ascertained that they have all been drifted. The upper surface of the estuarine beds, however, does show an old soil penetrated by small roots. From the Forest-bed have been obtained the relics of a flora and a mammalian fauna, which seem to contrast strongly with the assemblage of northern and arctic shells in the immediately subjacent deposits. All the plants are living species, and with a few exceptions still indigenous to Norfolk. The forest-trees include maple, sloe, hawthorn, cornel, elm, birch, alder, hornbeam, hazel, oak, beech, willow, yew, pine, and spruce. Mr. Reid, to whose interesting and important memoir [1] I am indebted for these details, remarks that there is an absence of both Arctic and South European plants, and he thinks that the climate of the Forest-bed epoch was mild and moist, and little if at all colder than now. Amongst the large mammals that were contemporaneous with this temperate flora were elephants (*Elephas meridionalis*, *E. antiquus*), hippopotamus, rhinoceros (*R. etruscus*), horse, bison, boar, and many kinds of deer, bears, *Machærodus*, hyæna, wolf, fox, glutton, beaver, &c. The somewhat inconstant *Leda myalis* bed is of marine origin and overlies the Forest-bed series. It occurs in interrupted patches, in none of which does the thickness of the deposits exceed twenty feet. Few fossils occur, and from the character of these it would seem certain that the separate exposures of the so-called *Leda myalis* bed cannot all be of precisely the same age. In one place, for example, the bed is represented by a mass of sand and gravel, the lower portion of which is full of oysters with the valves united. The species found associated with the oyster at this place (Lower Sherringham) are still natives of British seas. At another locality (West Runton) certain

[1] 'The Pliocene Deposits of Britain,' *Mem. Geol. Survey*, 1890.

ravels on the same horizon have yielded two arctic shells—
eda *myalis* and *Astarte borealis*—together with a few
ritish forms of no special significance. According to
rofessor Otto Torell, cited by Mr. Reid, the oyster-bed at
herringham can scarcely be of the same age as the bed at
unton—for the oyster is sensitive to cold, and does not
ve in the seas where *Leda myalis* and *Astarte borealis*
ourish. From this and other evidence 'it is possible,'
r. Reid remarks, 'that the different sections of the *Leda*
yalis bed are fragments of the marine deposits belonging
a period of considerable length, during which the depth
water varied and the climate changed.' Let me note two
lditional facts, which are not without significance:—*Leda*
yalis does not occur in any of the underlying Crag-beds,
hile *Ostrea edulis* is not found in the Weybourn and
hillesford Crags, though common lower down in the Plio-
ne series.

From the foregoing brief summary of the evidence it is
ovious that the Pliocene deposits of eastern England have
en accumulated under changing geographical and climatic
onditions. During the Coralline Crag period a considerable
art of south-east England must have been under water,
nd the same was the case with northern France and the
djacent Low Countries. The North Sea had then a wider
onnection with more southern seas than is now the case—
he whole facies of the Coralline Crag fauna denoting warm-
emperate conditions. Eventually, however, free communi-
ation with southern waters was interrupted—the sea
etreating from hitherto submerged areas, and allowing
England to become united to the Continent—while at the
ame time the German Ocean remained widely open to the
orth. The temperature of the sea now began to fall, and
he southern forms of marine life gradually died out—their
laces being taken by immigrating northern forms, until by-
nd-by the whole fauna of the North Sea acquired an arctic
acies. This lowering of the temperature seems also to be
ndicated by the occasional occurrence in the deposits of
rratics which were probably dropped from floating ice.
Continued retreat of the sea next laid bare the southern half
f the North Sea basin, and a large river—the ancient Rhine

—flowed over the new-made land and deposited its alluvial formations (the Forest-bed series) along the margin of what is now East Anglia. Mr. Reid is of opinion that the sea into which that river flowed was at this time occupied by the arctic fauna of the Weybourn Crag—a conclusion which seems rather startling. It is supposed that the gradual refrigeration to which the fauna of the Pliocene marine deposits bear witness was not altogether the result of a general climatic change. The cutting off of all connection with southern waters which took place in the Red Crag period, and the direct cooling action of currents from the north, would doubtless, as Mr. Prestwich has pointed out, affect the temperature of the North Sea. And according to Mr. Reid it is probable that 'the change in fauna was principally due to the sea being fully open to the north, so that there was a constant supply of arctic species brought by every tide or storm, while at the same time the southern forms had to hold their own without any aid from without; and if one was exterminated it would not be replaced. . . . The fact that not a single southern species appears for the first time in the Fluvio-marine, Chillesford, or Weybourn Crags seems clearly to show that they could not migrate into the district, owing to some barrier.' He then goes on to show that this barrier—the conversion of the southern half of the North Sea into land—which prevented the immigration of marine species from the south, would on the other hand form a highway for land and fresh-water species. Southern forms could then spread down the valley of the Rhine—their march not being checked by the previous occupation of the British area by arctic types, for we have no reason to believe that there was any land-connection at this time between Britain and northern lands. It is owing to these peculiar geographical conditions 'that in the Forest-bed we find a distinctly southern fauna contemporaneous with an equally marked arctic marine fauna; the plants at the same time showing that the climate was much the same as that of Norfolk at the present day, though perhaps more continental, *i.e.* hotter in summer and colder in winter.'

This is a conclusion which can hardly be accepted. How is it possible that, with arctic waters laving the east coast

England, such a flora as that of the Forest-bed could have)urished in Norfolk? If the North Sea was as cold as the esence of an arctic fauna implies, the Gulf-Stream Drift ust have been far removed from our west coast. In place of arm water from the south, a cold current from the north ust have washed the shores of north-west Europe, just as ı arctic current to-day washes the coast-lands of Labrador. is impossible that under such conditions a temperate imate could have obtained in England. An arctic fauna ving in the North Sea implies an arctic and boreal climate ɪr Britain, and I cannot believe, therefore, that the flora of ıe Forest-bed was contemporaneous in our area with the una of the Weybourn Crag and Chillesford Clay.

But let us look at the actual facts; the Forest-bed overlies ıe Weybourn Crag. Surely, then, the latter is older than e former—the two cannot be contemporaneous. Mr. Reid s anticipated this obvious objection to his explanation of e facts, and endeavours to meet it by pointing out that the ost typically southern of the fresh-water molluscs of the orest-bed occur also in the Weybourn Crag mixed with the ıaracteristic marine shells of that deposit; while several of e latter are met with in the Forest-bed. But surely this idence is hardly sufficient to establish his contention that e faunas of those two separate divisions of the Pliocene stem 'lived in adjoining districts during the same period.' he fresh-water shells in the Weybourn Crag may have been rried for a long distance from the south. Some years ago, hile watching the formation of ground-ice in the Tay near erth, I observed a valve of the river-mussel (*Unio margariferus*) brought to the surface by a detached mass of ice and rried down stream. It is quite conceivable, therefore, that ıells of fresh-water and even of land molluscs might have een transported in this way for long distances during the rmation of the Weybourn Crag. Either *Corbicula* and *ithoglyphus* were thus introduced to that Crag, or, what is uite probable, these shells may be derivative from the orwich Crag or from some other bed no longer in cistence.[1]

[1] I am inclined to think that we may attribute too much importance to the timony of river-shells as to climatic conditions. There can be no doubt that

The arctic shells occurring in the Forest-bed prove nothing as regards climate, for it cannot be denied that one and all have most probably been derived from the underlying Weybourn and Chillesford Crag. If it be objected that the occurrence of the narwhal (*Monodon monoceras*) in the Forest-bed is indicative of arctic or boreal conditions, I would point out that this cetacean has within recent times been stranded on the coasts of Britain—one having been seen in the Wash (Licolnshire) in 1800. Neither can the presence of the Walrus (*Trichechus Huxleyi*) be taken as certain evidence of an arctic or boreal temperature, for even in the present century it has been killed in the Outer Hebrides and in Orkney ; and there does not appear to be any reason why t might not frequent lower latitudes, were it not for man's interference. One of the marine fish known from the Forest-bed is the tunny (*Thynnus thynnus*), which now lives in warmer seas than ours. Mr. Reid suggests that the single vertebra found may be that of a stray individual, 'like those that visit our coast at short intervals, and stray even as far north as Shetland.' But these modern cases are not parallel with that which he supposes. According to him the North Sea in Forest-bed times was occupied by an arctic fauna, the presence of which would imply a cold current from the Northern Ocean flowing past the Atlantic coast of the British area. Now it is very improbable that under such conditions the tunny could have performed the journey required of it by Mr. Reid. It is not wonderful that now-a-days a tunny should occasionally travel north with the Gulf Stream Drift as far as the Shetlands, but it is hardly credible that if no Gulf Stream washed our coasts, this fish would

many land- and fresh-water forms of life- vegetable and animal—were driven out of northern and north-western Europe during the Glacial Period. Most of the land- and fresh-water molluscs reappeared in postglacial times, but amongst the fresh-water forms which did not return were *Corbicula fluminalis* and *Lithoglyphus fuscus*. The latter lives in the Danube, but surely that is no proof that it could not have tenanted the Rhine when an Arctic fauna occupied the North Sea. *Lithoglyphus naticoides*, at present a native of the river Bug, Dnieper, Dniester, and Danube, has recently been discovered in the 'lower diluvium' of Berlin. It is not known in the postglacial and recent deposits of North Germany ; but within the past few years it would appear to have again immigrated into Brandenburg. I am therefore not inclined to attribute much importance to the occurrence of this genus in the Weybourn Crag. (See Gottsche, *Sitzungs-Ber. d. Ges. Naturf. Freunde zu Berlin*, 1886, p. 7; *Zeitschr. d. deutsch. Geol. Ges.* xxxviii. 1886, p. 470.)

be tempted to go as far north as Ultima Thule in the face of an Arctic current. I see no reason, therefore, for supposing that the tunny of the Forest-bed was a stray individual. Its testimony is in keeping with the evidence of genial conditions furnished by the terrestrial fauna and flora, while the occurrence of narwhal and walrus is not opposed to that evidence.[1]

The story told by the English Pliocene deposits, however interesting and suggestive, is obviously incomplete, and we have probably much to learn before we can be assured as to the general succession of events within the North Sea area during the Pliocene period. Some deep borings at Amsterdam passed through a thickness of more than 1,000 ft. of sand, gravel, clay, &c., the lower half of which, according to Dr. Lorié, must be assigned to the Pliocene, and probably to the general horizon of our Red Crag. In these deposits, however, several arctic shells occur, which would seem to indicate colder water than that in which the fauna of the English Red Crag flourished. Mr. Reid thinks it is possible that the arctic shells referred to may point to the presence of a cold area in the Pliocene sea—in other words, to a deep depression on the sea-floor. But, as Mr. Reid admits, the deposits passed through by the borings afford no trace of deep-water conditions. In the face of this evidence and the somewhat equivocal character of that yielded by the Newer Pliocene of England, we may be allowed to doubt whether the presently accepted explanation of the facts can be true. At all events the evidence as it stands can be interpreted in another way. I am therefore inclined to favour the view that the Chillesford and Weybourn Crags represent a cold period which was succeeded by an epoch of genial conditions, during which the Forest-bed was accumulated. This conclusion, as will be shown later on, harmonises with what is known as to the earliest glacial and interglacial accumulations of the Continent. Nor is it without direct evidence in its favour. It will be remembered that in the marine beds overlying the Forest-

[1] As the marine arctic shells in the Forest-bed have almost certainly been derived from the underlying Crag, it is not improbable that the remains of the narwhal and the walrus may also be derivative.

bed we come upon the common oyster in considerable abundance, although no trace of this mollusc occurs in the subjacent Weybourn and Chillesford Crags. It is present, however, on lower horizons in the Pliocene. Note also that *Leda myalis* appears for the first time in the marine deposits above the Forest-bed. Surely these are suggestive facts. The oyster which flourished in the North Sea before the period of the Chillesford Crag appears then to have died out, and to have been re-introduced after the Forest-bed epoch, when the conditions had become more favourable. Ere long, however, the temperature again fell, and arctic molluscs, amongst them a new-comer (*Leda myalis*), took possession of our seas.

According to my interpretation of the evidence therefore, the Chillesford and Weybourn Crags mark the culmination of the cold conditions which began to manifest themselves in Red Crag times. There is no unequivocal evidence to show that land-conditions existed in the southern half of the North Sea basin during the formation of the arctic marine Crag-beds. After the deposition of these beds, however, the climate changed, and with the advent of genial conditions the sea retreated northwards and left a wide land-surface across which flowed the ancient Rhine. Afterwards, when the climate again changed, the sea re-advanced. At first the temperature of the water was such as to favour a marine molluscan fauna similar to that which now lives off the English coasts. By-and-by, as the cold increased, another invasion of arctic molluscs took place, and the sea rose to some 50 ft. or so above its present level. The reader may recall the evidence of somewhat similar climatic and geographical changes furnished by the glacial and interglacial accumulations of Scotland. We saw that in that country the advent of a cold epoch was invariably heralded and accompanied by submergence, while genial conditions were just as constantly attended by retreat of the sea and increased extension of the land. In the phenomena connected with the later Pliocene and early Pleistocene deposits of East Anglia we seem to be confronted by a like remarkable succession of events. The cold arctic marine conditions of the Upper Crag are succeeded by the wide land-surface and

enial climate of the Forest-bed, while those conditions in neir turn are followed by submergence immediately anterior ɔ the advent of a great *mer de glace*.

Whatever doubt we may have as to the character of the hanges that took place during the accumulation of the ıpper members of the Pliocene, there can be none as to the vents that succeeded the formation of these deposits. For mmediately above the youngest Pliocene comes the remark-ble stratum known as the Arctic Fresh-water Bed, in which Dr. Nathorst, the well-known Swedish naturalist, discovered n 1872[1] leaves of the arctic willow (*Salix polaris*) and other emains; and similar finds have since been made by the Geological Survey at various localities. Besides the arctic villow and other northern plants, the same stratum has ielded land and fresh-water shells (such as *Succinea putris, S. blonga, Helix hispida, Pupa muscorum, Valvata piscinalis, Pisidium Henslowianum*, &c.) and bones of a ground-squirrel *Spermophilus*), hitherto the only vertebrate met with on his horizon. It is obvious that a decided 'break in the uccession' must occur between the Forest-bed with its tem-erate flora and fauna and this arctic fresh-water bed with ts high northern forms. The flora of the former, as we ave seen, betokens a climate as mild as that of Norfolk at resent, while that of the latter implies, according to Mr. Reid, a lowering of the temperature by about 20°—a diffe-ence as great as that between the south of England and the orth Cape in our day.

The accumulations next in order point to a still further crease of cold conditions. They consist of a series of oulder-clays with associated sands and gravels. In the omer district the following is the succession as deter-ined by the Geological Survey:—

7. Boulder-gravels and sands: unfossiliferous.
6. Sands and loams, containing many shell-fragments and a few perfect shells.
5. Boulder-clay or stony loam, usually highly contorted ('contorted drift'), about 30 ft. thick: contains fragments of shells.
4. Fine sands, false-bedded, unfossiliferous; reaching in places 40 ft. in thickness.
3. Till or boulder-clay, containing much chalk, with sporadic shells of derivative origin.

[1] *Öfversigt af kongl. Vet.-Akad. Förh.* 1873, p. 18.

2. Intermediate beds; clays and marls, well laminated and ripple-marked, with seams of fine false-bedded sand: unfossiliferous.
1. Till or boulder-clay, with many broken, crushed, and striated marine shells.

The boulder-clay or stony loam (No. 5) is remarkable on account of its highly contorted structure, and for the presence in places of very many boulders of chalk, varying in size from a few feet to upwards of 180 yards in length, and most of which appear to have been derived from the Cretaceous formation of the same neighbourhood. It rests,

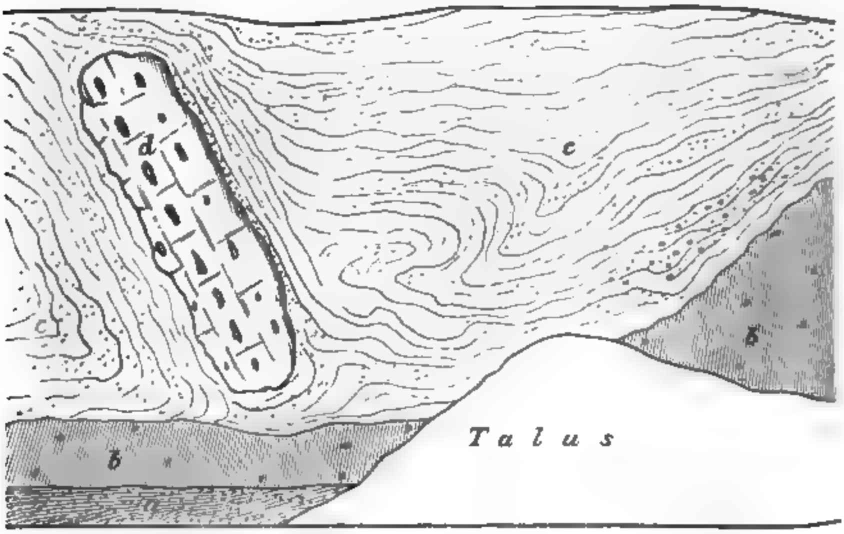

Fig. 64. Section of drift-deposits near Runton Gap, coast of Norfolk, north-west of Cromer. *a*, false-bedded fine yellow sand; *b*, dark blue till; *c*, 'contorted drift;' *d*, large erratic of chalk with flint nodules.

Mr. Reid says, on an eroded surface of any of the older beds, and often ploughs deeply into them. It resembles in general composition the underlying tills (1 and 3), but shows a kind of pseudo-bedded structure—such as might have resulted if the materials deposited in heaps had subsequently been flattened out into lenticular masses. Mr. Reid could find no clear evidence of the sedimentary origin of the accumulation, and the included shell-fragments and shells, he remarks, are obviously derivative. In short, the 'contorted drift' of the Cromer Cliffs is only a peculiar form of

ɔund-moraine. It is largely made up of a confused mass deposits of different ages—of chalk, of Pliocene beds, and various Pleistocene accumulations. All these have been nbled together in the wildest manner, and yet it is note-›rthy that this 'contorted drift' usually rests with a hori-ntal junction on quite undisturbed beds. It is impossible, ›wever, to convey by verbal description an adequate ›tion of the character of this remarkable accumulation, ıd I must refer the reader to Mr. Reid's monograph,[1] in hich he will find admirable sections, clearly depicting the eneral appearance of the contortions seen in the Cromer 'liffs. Reference should also be made to the descriptions ;iven by Mr. S. V. Wood and his coadjutors, Messrs. Rome ınd Harmer.[2]

For a long time geologists were of opinion that the phenomena of the contorted drift were due to the action of floating ice. That was the view adopted in the earlier editions of this work. The underlying 'Till' I recognised as the ground-moraine of an ice-sheet, while the superjacent 'Contorted Drift' represented, as I then thought, the deposits of retreat, —laid down by the first great ice-sheet while it was melting away. The contortions I attributed, as others had done, to the grounding of icebergs detached from the terminal front of the retreating *mer de glace*. But in 1880 Mr. Reid, after careful survey of all the evidence, came to the conclusion hat the remarkable disturbances in the Cromer Cliffs had been aused by the pressure of an ice-sheet. Our examination of ıe glacial phenomena of Scotland, as we have seen, led to ıe conclusion that the North Sea basin during the epoch of aximum glaciation must have been filled with a *mer de ace* derived from confluent ice-streams coming from Scot-nd and Scandinavia. In the northern part of the basin e direction of the ice-flow was towards the north-west, hile south of the Firth of Tay the ice followed a southerly d south-westerly course. It is to the action of this ice-

[1] *Mem. Geol. Survey*, 1882; Expl. of Sheet 68 E.

[2] *Geol. Mag.* vol. v. p. 452; vol. vii. pp. 17, 61; vol. viii. pp. 92, 406; vol. pp. 153, 171, 352; *Palæontographical Society*, vol. xxv.; *Brit. Assoc. Rep.* 58; *Quart. Journ. Geol. Soc.* vol. xxii. p. 546; vol. xxiii. p. 89; vol. xxiv. 146; vol. xxv. p. 446. A complete list of papers referring to the Cromer tions is given in *Mem. Geol. Survey*, 'Geology of the Country around rwich.'

sheet that Mr. Reid attributes the formation of the boulder-clays and the contortions of the beds which are so clearly exposed in the cliffs at Cromer. It is interesting to find, he remarks, that the strike of the larger folds in the contorted drift on the coast points to a force acting from the north-east. The direction of ice-movement is moreover indicated by the occurrence in the glacial deposits of erratics of Norwegian rocks. The large masses of chalk have evidently been derived from the chalk in the immediate neighbourhood—none of the boulders, according to Mr. Reid, need have been moved more than a few hundred yards from its original bed. He notes as a significant fact that these chalk-boulders are entirely confined to that part of the coast on which the solid chalk (or chalk in place) is at a sufficiently high level to be occasionally ploughed into by the 'contorted drift.' When the ice-sheet got at the chalk-beds, it seems in places to have first forced these up into a long fold which, under continued pressure, was gradually bent over in the direction of movement, until eventually the top of the inverted fold was sheared off, and the detached mass driven up an incline and forced into the overlying ground-moraine. The masses of reconstructed chalk so common in the contorted drift are probably, Mr. Reid thinks, only 'a later stage of the transported boulders, in this case so shattered and mixed with clay that they form a sort of transition to an ordinary boulder-clay.' There seems to be no doubt, in short, that this contorted drift eventually passes into the 'great chalky boulder-clay' which, as we shall see presently, covers a wide area in the south-east of England.

A word now as to the other beds of till, gravel, and sand which are associated with the contorted drift. The tills (1 and 3, page 337) are obviously of the nature of ground-moraine, the traces of lamination which they show having nothing to do with aqueous sedimentation. All these appearances of bedding are simply the result of shearing and fluidal movement under compression, like the pseudo-laminated structure so often seen in the Scottish ground-moraines. Everywhere throughout the Cromer glacial deposits we see evidence of lateral thrust—the apparent thickness of the beds being often much exaggerated in this way. The intercalated sheets of

d and gravel are in all probability of subglacial origin—
ıting to the flow of water under the ice-sheet. They are
ossiliferous, which is good proof that they are not marine.
ɜ 'sands and loams' (6) contain, it is true, many shell-
gments and some perfect shells. But these, there is every
ɜon to believe, are derivative. The beds share in the con-
:ions described above, and therefore cannot be of later date
n the underlying boulder-clay. In short, it would seem
t all the Pleistocene accumulations exposed in the Cromer
ffs are of glacial and subglacial origin, and belong to one
l the same epoch of glaciation.[1]

[1] For the general direction of glaciation in England see Plate I.

CHAPTER XXV.

GLACIAL PHENOMENA OF ENGLAND—*continued.*

The great chalky boulder-clay—Mr. Skertchly on its origin—The glacial accumulations of Holderness and Flamborough Head—Old sea-cliffs, &c. at Sewerby—Shell-bed at Speeton—Mr. Lamplugh's and Mr. Reid's descriptions of the overlying glacial deposits—Fossiliferous beds above the older glacial series—Boulder-clay of Hessle—General succession of the glacial and interglacial beds.

IN the last chapter we have been studying the glacial accumulations which were the first to be laid down after the close of the Pliocene period. We saw that the most prominent member of the series exposed in the Cromer Cliffs was an accumulation crowded with great blocks of chalk and chalk-débris. Away from Cromer that deposit is represented by what is known as the great chalky boulder-clay, which covers extensive areas in Lincoln, Norfolk, Suffolk, Cambridge, Bedford, Hertford, and Essex.

The boulder-clay in question is an unstratified mass of pale dirty grey clay, more or less abundantly crammed with fragments of chalk and flint. Amongst these may often be detected stones which have come from greater distances, such as fragments of Jurassic rocks, white sandstone, basalt-rock, quartz, granite, and other crystalline rocks. None of the stones seems to be water-worn, save such as may have been derived from gravelly beds in the Tertiary formations, their general appearance being similar to that of erratics in the till of Scotland and north of England: they are blunted and subangular, often well smoothed, and frequently striated. Now and again lenticular beds and patches of sand and gravel occur in the clay, just as in the Scottish till. Traces of bedding in the mass are very rare, according to my friend Mr. Whitaker, and are chiefly noted towards the bottom of the deposit. This 'bedding,' such as it is, appears to

be defined by mere local changes of colouring—due in all probability to shearing and fluidal movement of the mass under pressure. Here and there, however, the clay contains at its base irregular layers of gravel, which sometimes attain a thickness of several feet. In the same position beds of laminated brick-clay also occasionally occur. These beds evidently form part and parcel of the boulder-clay, and are quite analogous to the similar beds which are found underlying and intercalated with the Scottish tills and the similar accumulations at Cromer.

In a number of good sections which I visited under the guidance of my colleagues on the Geological Survey while they were engaged in surveying Norfolk and Suffolk, I noticed that the clay was as hard and compressed as any till I have seen, and here and there it appeared to be squeezed down into underlying strata of chalk and other rocks. It is of very variable thickness, being sometimes only a few feet, and at other times swelling out to 100 ft. or more. The junction-line between it and the underlying strata is always more or less well defined, but every one who has studied it has been struck with the unevenness of the surface upon which it rests—for while here and there it may repose upon a level platform over a considerable area, it ever and anon ploughs deeply into the strata underneath. Very frequently it seems to cut out all the underlying glacial sands and gravels so as to repose directly upon Tertiary or Cretaceous formations. I may add that the deposit has not been traced farther south than the heights overlooking the valley of the Thames.

The chalky boulder-clay of Lincolnshire and eastern Yorkshire answers in every respect to the deposit which has just been described, and there can be no doubt that the one is merely the continuation of the other. Messrs. Wood and Rome [1] describe that seen in Holderness as 'a lead-coloured clay abounding in chalk-débris, accompanied by stones and boulders from all sorts of rocks.' It 'rises up in only a few parts of the coast, and is overlapped in every direction by another thick bed of boulder-clay to which in most of its exposures it presents a very denuded surface, rising up

[1] *Quart. Journ. Geol. Soc.* vol. xxiv. p. 146.

beneath it in bosses, and in some places divided from it by beds of gravel, &c.' At Dimlington I noticed that this lead-coloured till was not only very tough and well charged with stones, most of the harder ones of which showed glacial striæ, but it was also quite unstratified. Here and there, however, there occurred lenticular and irregular layers and patches of shingle, gravel, sand, &c., just as in normal Scottish till. Now and again I also observed that peculiar 'curled arrangement' of the stones in the clay which has been described in connection with the till of Scotland, and which points to the *moraine-profonde* origin of the deposit. The same curious relation between the size of the stones, and the coarseness of the striæ imprinted upon them, likewise obtains in the chalky boulder-clay of Holderness.

Although the chalky boulder-clay appears to be obviously the ground-moraine of an ice-sheet, yet there are some geologists who still maintain that it owes its origin in some mysterious way to the action of floating ice which sailed over a large part of England during a supposed period of depression; no one, however, as far as I know, has ever entered so far into details as to show in what precise manner the deposit could have been formed by icebergs. Those who still fondly cling to the notion that boulder-clay is of marine origin are necessarily driven to use liberties with our mother Earth, and think nothing of elevating and depressing the land for hundreds of feet to suit the necessities of their hypothesis. Thus Mr. A. J. Jukes-Browne,[1] in attempting to account for the origin of the chalky boulder-clay and certain overlying boulder-clays, which have yet to be described, has no hesitation in assuming that each of these indicates a submergence of the land. He drowns all eastern and midland England to a depth of 600 ft. in order to explain the distribution of the great chalky boulder-clay. This submergence is supposed, for some unknown reason, to have 'tended to ameliorate the climate, and to have cut off the supply of boulder-clay.' Next we have the land pushed up again to some extent, and glacial conditions renewed. Then another depression succeeds, to allow of the deposition of more boulder-clay, and eventually to cause the final dis-

[1] *Quart. Journ. Geol. Soc.* vol. xli. p. 130.

pearance of glacial conditions; after which the much-
ɔwned land is re-elevated for the last time. I must not
ıit to add, however, that Mr. Jukes-Browne confesses that
ese views 'are purely theoretical, and may not represent
ything like the actual sequence of events.' When such
ıde views can be entertained by an experienced geologist,
seems not improbable that others, who have not had so
ıny opportunities for field-observations, may still think
ıt the chalky boulder-clay can be explained by the action
floating ice during submergence. For their benefit,
refore, I reproduce here some excellent notes which Mr.
B. J. Skertchly kindly supplied for the last edition of
s work.

Mr. Skertchly says: 'The district to which the following
es refer is over 2,000 square miles in extent, and lies
hin the counties of Lincoln, Rutland, Leicester, North-
pton, Huntingdon, Norfolk, and Suffolk. The Fenland
elf occupies parts of all the above counties excepting
tland and Leicester, and embraces an area of over 1,300
ıare miles, all of which, with very trifling exceptions, is
vered with Post-tertiary deposits.

'The lie of the older rocks must be briefly described
fore entering upon the questions relating to the newer
ds. The strike of the Jurassic rocks is roughly north and
ıth, as is also that of the Cretaceous beds along the south
d east of the Fenland; but upon the north, in Lincoln-
ire, the strike assumes a westerly trend so as to overlap
e Jurassic beds. The two great clays, the Oxford and
meridge[1] (which throughout this area come together in
ısequence of the local absence of the Coral Rag), underlie
ıst of the Fenland, the former capping the ground to the
st thereof, while the latter takes the ground on the north-
st and south-west. The Gault Clay is found beneath the
ns in parts of Cambridgeshire and Norfolk only, and the
alk underlies very little of the area, but bounds it on the
ıth, east, and north-east.

'Confining our attention for the present to the Chalk,
meridge Clay, and Oxford Clay, we find that the boulder-

[1] See Table of Systems, Appendix A, for geological position of these and
er Jurassic and Cretaceous beds.

clay lying upon these rocks partakes of their physical character. Thus upon the Chalk the boulder-clay is very chalky, and indeed in some places, as at Mareham-le-Fen in Lincolnshire, and Thetford in Norfolk, it is almost entirely made up of that substance; at the former place it is quarried and burnt for lime, and at the latter the presence of seams of clay and ice-scratched flints alone enables us to discriminate between it and the Chalk beneath. The Kimeridge Clay is darker than the Oxford Clay, and we accordingly find the boulder-clay which reposes upon the former is darker than that which lies upon the latter. Where boulders are rare it is sometimes very difficult to distinguish the boulder-clay from the older rocks.[1]

'I have chosen these examples as being most readily observed around the Fens. But similar remarks apply to all other formations upon which I have mapped boulder-clay. For example, the light-blue Upper Lias Clay of Leicestershire impresses its character upon the boulder-clay which overlies it, and the other members of the Liassic group where they are in force behave in a similar manner. The great Lincolnshire (Inferior) Oolite limestone around Melton Mowbray yields so large a quantity of material to the boulder-clay there that I have been in doubt as to whether the deposit might not be faulted limestone.

'These peculiarities are at once, and correctly, expressed by the statement that the ingredients of the boulder-clay are for the most part supplied by rocks, upon or near which it reposes. That this is actually the case, and not an accident of colour, is further attested by the included fossils; *Gryphæa dilatata* and *Belemnites Owenii*, for example, are abundant upon the Oxford clay, and *Ostrea deltoidea* upon the Kimeridge Clay. It rests with the upholders of the marine theory of this boulder-clay to explain by what "selective affinity" icebergs shed Oxford Clay detritus chiefly upon Oxford Clay, and so on with other rocks.

'By a happy accident it can, however, be proved that much of the boulder-clay around Brandon has been formed in that immediate vicinity, that it has not moved more than a few

[1] It is difficult to express this forcibly enough in a few notes: examples and localities could be multiplied *ad infinitum*.

iles, and that the material has never been exposed to the
e action of the weather. Brandon is the seat of the gun-
nt industry, and from Neolithic[1] times flint has been un-
terruptedly mined for in the neighbourhood. The beds of
nt are five in number, and each possesses peculiarities which
nder its recognition easy. These layers of flint are quite
cal, not exceeding in area ten square miles. The flint to
available for gun-flint making must be perfectly sound, and
re in colour. An exposure to the weather for a few months
tirely spoils it. Now in the boulder-clay near Brandon,
rge pieces of each of these kinds of flint are found measur-
g occasionally as much as a yard over. They are perfectly
riated; but the coats have suffered hardly any diminution
thickness, and the stone is as sound and the colour as good
in that freshly dug from the flint-pits; indeed they are
tually used by the flint-knappers. These flints can only
ve been derived from the immediate vicinity; it is clearly
possible that they could have been dropped by icebergs,
the glacier from which the berg broke away must have
cupied the same *dry* ground as the iceberg *floated over* and
elted upon! and it is equally impossible that the flints
uld have formed part of a lateral moraine, or they would
ve become shattered by exposure to the weather.[2] The
ly explanation which accounts for their presence and con-
tion is that they formed part of a ground-moraine beneath
ice-sheet.

'While engaged in mapping the Jurassic rocks of north
orthamptonshire, Lincolnshire, Rutland, and Leicester-
ire, we often met with a very puzzling phenomenon which
w appears very easy of solution. From the Inferior Oolite
the Cornbrash the beds there consist of intercalated beds
clay and limestone averaging say fifteen feet in thickness.
e boulder-clay has suffered considerable denudation, and is
quently absent from the narrow outcrops of the limestones
t present upon the clays, so that we used jokingly to say

[1] The age during which the ancient inhabitants of Britain used weapons
implements of stone comprises two periods; viz. the Old Stone or Palæo-
lic, and the New Stone or Neolithic periods.

[2] Many of these flints were dug last summer (1875), and the exposure to a
gle season's frost has rendered them unfit for flint-knapping: how then could
ey have withstood exposure to the rigours of arctic winters upon the surface
glaciers?

"the boulder-drift sticks to the clays." The appearance is represented in the annexed cut. The hard limestones stand out and the soft clays have been worn away. I know of no other power than a grinding and scooping one which could have cut out the Jurassic clays and filled the hollows up with boulder-clay. Of course ordinary atmospheric action would

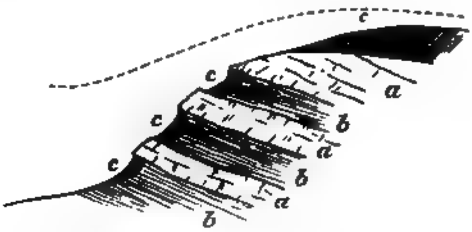

Fig. 65.—Drift sticking to clays. *a, a, a*, **limestone ;** *b, b, b*, **clays ;** *c, c, c*, **boulder-clay ;** *dotted line*, **indicates the original contour of boulder-clay.**

wear away the rocks in the same manner, but here everything tends to show that the scooping was contemporaneous with the filling up, and if icebergs or ordinary glaciers had done the work they would have left different tool-marks. The original contour of the boulder-clay is shown by the dotted line, and it is only in consequence of subsequent denudation that the phenomenon in question is revealed.

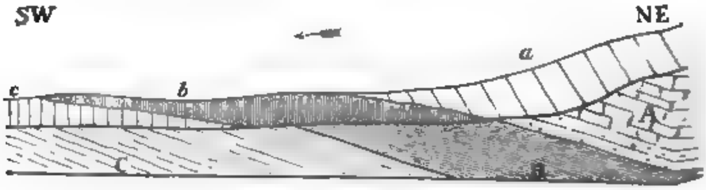

Fig. 66. - Exaggerated diagram section showing the relation of the boulder-clay to the subjacent rocks in Lincolnshire.

A, Cretaceous ; B, Kimeridge Clay ; C, Oxford Clay ; *a*, very chalky boulder-clay ; *b*, dark-blue Kimeridge-like clay ; *c*, light-blue Oxford-like clay.

'There is a remarkable modification of the law, that the physical character of the boulder-clay is dependent upon that of the subjacent rocks—a modification which evidently cannot be explained on the marine theory, nor yet on that of local glaciers. This is the invasion of the outcrop of one rock by the boulder-clay which is composed of some other

rock lying to the north-east.[1] This is best observed on the northern border of the Fens, where, in consequence of the overlap of the Cretaceous beds their strike runs in a north-west direction. Upon the Chalk to the extreme east the boulder-clay is very chalky, and it maintains this character across the narrow Greensand outcrops on to the Kimeridge Clay. We then get a deposit composed chiefly of Kimeridge Clay, and this is continued in like manner on to the outcrop of the Oxford Clay, when the boulder-clay assumes the character of that rock, as shown in the subjoined very exaggerated diagram-section. This peculiar arrangement can only be explained by supposing the ice-sheet to have flowed from the north-east to the south-west, that is to say *inland from the coast.* In this it agrees with the ice-marks along the north-eastern shores of England generally.

'I thought at one time that the chalk-surfaces beneath the boulder-clay might yield us "ice-pavements" similar to those found in the glaciated Palæozoic regions to the north. These I have not yet found, for the chalk was too soft to resist the grinding pressure of the ice, and consequently there is generally no sharp line of demarcation between it and the boulder-clay, but the former is broken up and mixed with sand and clay, forming a peculiar material locally known as *dead-lime*, which, I believe, is unknown in the south of England. This dead-lime passes insensibly into solid chalk below, and into boulder-clay or Palæolithic gravel (as the case may be) above; thus affording another proof of the local nature of the glacial clay. It is mostly composed of shattered chalk, and averages about three feet in thickness, and the marly cream-coloured portions form irregular-shaped pockets surrounded by the white dead-lime. Flints are abundant in it when the chalk beneath is flint-bearing, but in other cases they are rare or wanting. It is a significant fact that these flints seldom lie in a natural position, or as they would fall under the influence of gravity alone, but stand on end, or as the workmen say *edge-ways.* The general appearance is shown in the following figure, which forcibly suggests a motion from north-east to south-west. Many sections however, do not bring this out so clearly, because they are

[1] See *ante*, p. 78.

not in the right direction; but, so far as my observations have yet gone, the phenomena are pretty general. The edge-ways flints are quite un-weathered, and are often used by the flint-knappers.

'All of the above peculiarities are explicable solely on the land-ice theory, and are absolutely antagonistic to the marine hypothesis; hence, even if they stood alone they would yet be sufficient to negative the latter. But an equally powerful argument in favour of the land-ice origin of the boulder-clay is furnished by a consideration of the heights to which that deposit extends. Icebergs are merely fragments broken from the terminal fronts of glaciers which protrude into the sea, and the material they transport is part of that which

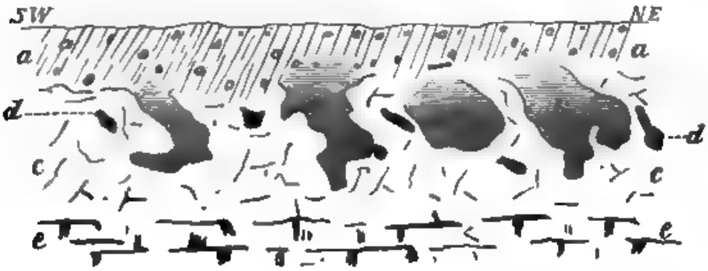

Fig. 67. Relations of the dead-lime, boulder-clay, and edge-ways flints.
a, boulder-clay; *b*, cream-coloured pockets of dead-lime; *c*, white dead-lime; *d*, edge-ways flints; *e*, solid chalk.

has fallen upon the surface of the parent glacier, or which has become frozen into its base. To produce iceberg boulder-drift two things are essential, namely, gathering-grounds from which the boulders are derived, and sufficient depth of water to float the bergs over the *highest* point upon which their burden is deposited. It follows from this that the material composing such boulder-clay must have been derived from rocks lying *in situ* at a higher level than the boulder-clay attains. Now the boulder-clay under consideration has received the name of the "great chalky boulder-clay"—***great***, because of its wide-spread extent, which is not less than 3,000 square miles and probably much more, and ***chalky*** because it is throughout characterised by the presence in greater or less abundance of fragments of chalk. It caps all

high grounds of the eastern and midland counties, ɪing an elevation of at least 500 ft. above the sea- and it is also found (at Boston) 600 ft. below that Now we may be sure that if it be iceberg-drift, there exist an extensive gathering-ground of Chalk having an tion of more than 500 ft. But where is it? Certainly in western Europe, for the Chalk does not attain so an elevation except in a few isolated spots. It is clear a few scattered islands could never feed the great ers whose fragments formed the chalky boulder-clay, ɪence we may at once dismiss the marine theory on the ɪd that the rocks which supplied the material of the ler-clay would be almost entirely submerged beneath a apable of floating icebergs over hills 500 ft. above the ›nt sea-level.[1]

I think it quite unnecessary to add more facts to prove only the land-ice theory can account for the phenomena e boulder-clay of this district, and should not have dealt them at so great a length had not recent writers taken most for granted that the marine theory would alone ld water."

The boulder-clay, however, like its relative the Scottish is not one and undivided, but contains intercalated beds ınd and stratified clay and loam in places. They are, ever, so precisely similar to the Scottish intercalated that I will only give three sections for comparison.

The first is at Little Bytham in Lincolnshire, where the on is as follows:—

	ft.
Boulder-clay, thickness unknown, say	30
Sand and gravel	16
Boulder-clay	33
Sand and gravel	88
Boulder-clay	
	167

The second section is from a boring at Boston, and is ırkable for the thickness of the beds and the depth to h they descend, the top of the section being only twenty above the sea:—

[1] The Oxford and Kimeridge Clays, which supply so large a bulk of the er-clay, would be *entirely* submerged.

	ft.	in.
Fen-beds	24	0
Boulder-clay	440	0
Sand, gravel, and clay	14	0
Clay	7	0
Coarse gravel	5	6
Boulder-clay	19	6
Coarse gravel	19	0
Clay	7	0
White sand	11	0
Brown loam	6	0
	553	0

'The third section is at Elvedon Gap, near Thetford, Norfolk, and is taken in the centre of a basin-shaped depression in the Chalk, which basin the recent beds fill up:—

	ft.
Sand lying unconformably upon, and cutting into, the subjacent bed	3
Boulder-clay	6
Grey clay	4
Blue clay	12
Rock formed of cemented loam	2
Laminated and contorted loam	3
Very fine gravel, stratified and contorted, with seams of loam	4
Loam as above	4
Boulder-clay	2
Gravel	2
Chalk	
	42

'The similarity of these sections to many of those described from Scotland in the earlier part of this work is very striking, and obviates the necessity for further description.'

Attention must now be directed to another series of coast-sections, in which glacial deposits are well exposed. The cliffs of Flamborough Head and Holderness are hardly less famous than those of Cromer, and have been visited and described by many enthusiastic observers.

As a rule, the base of the glacial series is not seen in these cliffs. In two places, however, we get a peep at certain 'infraglacial' deposits, which from many points of view are very interesting. Near Sewerby an old sea-cliff occurs buried underneath the lowest members of the glacial series. The cliff is an abrupt wall of chalk, some thirty or forty feet in height, and marks an old sea-margin, for at its base is found a beach composed of rounded stones, reaching

a thickness of four or five feet, and resting on a sea-cut platform of chalk. The shingle is made up chiefly of rolled fragments of chalk with a scattering of flint-pebbles, and a very few fragments of sandstones, quartzite, basalts, and black carbonaceous shale—none of these being more than two inches or so in diameter. The flints and the dark shale have probably drifted along the coast from the north; but the sandstones, quartzite, and basalts must have been derived from some other region—they are erratics. The bones of several extinct and no longer indigenous mammals and many sea-shells occur in these beach-deposits—the upper surface of which is not much above the present level of the highest tides. Resting upon the surface of the beach comes an irregularly bedded mass of marly clay (five feet thick) containing subangular lumps of chalk and streaks of sand—evidently, as Mr. Lamplugh remarks, talus and rain-wash from the adjoining cliff. Numerous land-shells and some mammalian bones and obscure traces of vegetation were seen in this 'rain-wash.' A mass of fine wind-drifted yellow sand, over twenty-five feet thick, and including a few angular blocks of chalk and an occasional bone, covers the rain-wash and beach-deposits, and sweeps up to the top of the buried cliff, where it is abruptly cut off by the overlying glacial deposits. The cliff-face behind this blown sand is finely smoothed and rounded, as if from the friction of the wind-driven particles.[1]

Again, at Speeton, an estuarine shell-bed occurs underneath the oldest of the glacial accumulations, at an elevation of 90 ft. above the present sea-level. This deposit has yielded a small assemblage of estuarine and marine shells, amongst which *Tellina balthica* is plentiful, showing, as Mr. Lamplugh says, that the beds were deposited in a period not far removed from glacial times.

It is obvious that the relation of the old beach at Sewerby and the estuarine bed at Speeton to the glacial series is an important question. Mr. Lamplugh has no doubt that they are both older than the oldest boulder-clay of that region. The presence of small erratics in the beach seems indeed

[1] See G. W. Lamplugh, *Proc. Yorks. Geol. and Polytech. Soc.* 1887, vol. ix. part iii.; *Quart. Journ. Geol. Soc.* vol. xlvii. p. 384; C. Reid, 'Geology of Holderness,' *Mem. Geol. Surv.* 1885.

to suggest derivation from some older glacial accumulation, but no earlier accumulation of the kind is known. Mr. Lamplugh mentions some other facts from which it is difficult to avoid the conclusion that these 'infraglacial deposits' must have been laid down before the formation of any of the boulder-clays of eastern England. He would therefore correlate the deposits in question with the *Leda myalis* bed of the Norfolk cliffs, which it will be remembered overlies the Forest-bed. This seems a reasonable conclusion. The *Leda myalis* bed, as we have seen, consists of various deposits which cannot be exactly contemporaneous. They only partially fill up the hiatus that separates the Forest-bed from the Arctic Fresh-water Bed. It is highly probable, therefore, that the Sewerby beach and the Speeton shell-bed belong in like manner to different stages of the same epoch —the former approximating closely in age to the Forest-bed, the latter being somewhat younger. The mammalian remains obtained from Sewerby are all Forest-bed forms, with the exception only of *Rhinoceros leptorhinus* (Cuv.) and *Cervus megaceros*, which last is a doubtful determination. The presence of the small erratics in the old beach need not surprise us. Similar erratics occur in many of the Newer Pliocene deposits. And it is obvious, moreover, that during the deposition of the Weybourn Crag the conditions in the North Sea were such that many erratics must have been distributed over the sea-floor by floating-ice. What more likely, therefore, than that some of these should be washed up at a later date and included in the shore-deposits then forming? The 'infraglacial' deposits therefore assure us that before the advent of the great *mer de glace* underneath which the oldest boulder-clay of Holderness was accumulated, mild and genial conditions obtained. The sea was occupied by a molluscan fauna like that of the present day, while the land was tenanted by elephants, rhinoceros, hippopotamus, hyæna, as well as by deer and oxen.

We turn now to the overlying glacial deposits. Many years ago these deposits, which cover extensive areas in eastern Yorkshire, were described and classified by Professor Phillips,[1] who grouped them into Lower and Upper Boulder-

[1] *Illustrations of the Geology of Yorkshire*, 1875.

clays with intermediate beds of gravel and sand. At a later date Messrs. S. V. Wood and Rome examined the same region, and recognised three separate boulder-clays with intervening stratified deposits.[1] More recently the district has been studied in great detail by Mr. Lamplugh[2] and mapped by the Geological Survey[3]—so that we are now very well-informed as to the character and succession of the glacial series in Yorkshire.

The lowest of the boulder-clays is that named by Mr. Wood the 'basement-clay.' It is dark green or bluish in colour, and contains many far-travelled erratics and only 'a moderate amount of local chalk.' Along with these occur numerous boulders, large and small, of various Cretaceous and Jurassic rocks. But the most characteristic erratics are irregular lumps, shreds, and masses of sand and clay, full of shells, which are often well-preserved. These inclusions were formerly believed to mark a regular horizon of aqueous deposition—the so-called Bridlington Crag—but Mr. Lamplugh has shown conclusively that they are not *in situ*, but are true erratics like the other boulders in the clay. The fauna of these shelly inclusions is distinctly arctic—more markedly boreal, according to Mr. Reid, than that of any other British deposit. A few of the species are at the present day confined to American seas. Shell-fragments and occasionally a perfect shell are scattered here and there in the boulder-clay itself. When the base of this boulder-clay is seen, it frequently rests on a jumbled and tumbled surface of chalk. Now and again, however, stratified deposits of silt and sand intervene between the chalk-rubble and the overlying boulder-clay.

Mr. Lamplugh and Mr. Reid are quite at one in believing that the basement-clay is the direct product of a great *mer de glace*, which 'seems to have crept in upon the land from the north-east, coming up out of the bed of the North Sea' (Lamplugh). The transported masses of shelly clay included in the till have evidently been scraped off the bed of

[1] *Quart. Journ. Geol. Soc.* vol. xxiv. p. 146.
[2] *Ibid.* vol. xlvii. p. 384. In this paper references will be found to earlier papers by Mr. Lamplugh, as well as to the works of other authors.
[3] 'The Geology of Holderness' (*Mem. Geol. Surv.*), which contains a copious list of papers, &c., dealing with the geology.

the sea, and the shells scattered through the till have obviously come from the same quarter. The broken and tumbled chalk-rubble doubtless owes its origin to the action of the ice, but, as Mr. Lamplugh has pointed out, it has not all been formed in this way. Before the region was visited by the *mer de glace* the exposed surfaces of the chalk must have suffered much disintegration, and we can readily understand how this loose detritus would be swept down by summer floods so as to accumulate in hollows and depressions of the surface. Mr. Lamplugh tells us that in the inner recesses of the Yorkshire Wolds, which were never overwhelmed by the ice-sheet, chalk-rubble often attains a considerable depth in high-lying depressions, where it has remained unmodified. But in the area invaded by the ice-sheet such superficial accumulations could not escape disturbance, but would often become mixed with erratic materials; while, as Mr. Lamplugh further informs us, the solid chalk itself was sometimes contorted below the chalk-rubble. He thinks that the occurrence of this rubble &c. under the basement-clay, at twenty feet below sea-level, and its position in some of the buried valleys of Flamborough Head, point to an elevation of the land during its formation. Mr. Lamplugh agrees with the late Mr. Wood that the basement-clay is the product of the major glaciation, and roughly equivalent therefore to the till at Cromer.

At Dimlington and near Bridlington the basement-clay is overlaid by stratified unfossiliferous deposits of clay and sand that vary in thickness from four or five up to more than twenty feet. They form an inconstant series—being often abruptly truncated and ploughed into by an overlying mass of boulder-clay, the so-called 'purple clay.' This latter is a characteristic till. It is usually very chalky near the bottom, but contains less chalk higher up. Far-travelled erratics are common, amongst them being boulders of Shap granite, which has not certainly been obtained in the basement-clay. Again, the purple clay contains none of those transported masses of shelly clay and sand, nor any of the Jurassic fragments which form so marked a feature of the basement-clay. Shell-fragments are sparsely scattered through the purple clay, but seem to be of less frequent occurrence in the upper than

the lower portion of the bed. According to Mr. Lamplugh, the purple boulder-clay when it is followed towards Flamborough Head becomes dovetailed with aqueous deposits, into which it eventually merges. So that there the basement-clay is overlaid by 'a complex and ever-changing series, often confusedly arranged, of silt, sand, gravel, and bands of boulder-clay. This series sometimes seems to pass gradually downwards into the basement-clay, but more often the junction is distinctly one of erosion. Its relation to the overlying upper clay (which will be described presently) is similarly variable—one section revealing a gradual passage, while another shows displacement and erosion at the junction.' Mr. Lamplugh therefore considers all the stratified deposits that immediately underlie the upper boulder-clay of Holderness (=the 'Hessle clay' of Mr. S. V. Wood) as contemporaneous with the purple boulder-clay. But this can hardly be the case. According to Mr. C. Reid, there occur in Holderness two independent series of gravels. One of these caps the higher elevations near the coast, and is obviously closely connected with the older boulder-clays, while the other consists of marine sands and gravels which dip regularly seaward beneath the upper boulder-clay. These marine deposits appear to have been deposited in an old bay—the limits of which are indicated by the 100-ft. contour-line, for above this the marine beds do not occur. 'The fauna of the marine gravels,' he says, 'is such as might have lived at the spots where the fossils now occur. It is usually purely marine; but opposite the gap in the Wolds through which the Humber flows fresh-water shells and bones of land-mammals occur abundantly, and fresh-water shells are also found at one other spot, opposite the mouth of a Wold valley in north Lincolnshire. If the gravels had been pushed up and reconstructed by the ice, as suggested by Mr. Lamplugh, it is curious that the slight variations in the fauna should agree so closely with variations in the local conditions where the gravel is now found, and not with variations we should expect to find farther seaward.'

The first detailed description of these fossiliferous gravels was given by Professor Prestwich, and at a later date we have some further details from Messrs. Wood and Rome.

The general result of these observations went to prove that the gravels rested upon and were covered by boulder-clay; while the character of the fossils indicated a climate not colder than the present. These earlier observations have been incorporated with his own account of the evidence by Mr. Clement Reid in his excellent 'Geology of Holderness,' to which the reader is referred for details. Mr. Reid tells us that the molluscan fauna is slightly northern but not arctic. Out of sixty-one species, ten or twelve do not now range so far south as the southern half of the North Sea, while the rest, with two exceptions, are living British forms, many of which do not range far north Of the two exceptions, one (*Tellina obliqua*), represented by a single valve, is an extinct Crag species, while the other is the fresh-water *Corbicula* (*Cyrena*) *fluminalis*, now extinct in Europe, but still living in the Nile and various rivers of Asia. The latter shell occurs in great abundance in the gravels at Kelsea Hill and the neighbourhood. The mammalian remains include those of *Elephas primigenius*, *Cervus tarandus*, *Bison priscus*, *Rhinoceros leptorhinus*, and *Trichechus rosmarus*.

It is worthy of note that at Hessle certain gravels, long ago described by Professor Phillips, are met with resting upon chalk and covered by boulder-clay. These have yielded *Elephas primigenius*, *Rhinoceros*, *Equus caballus*, *Cervus*, and *Bos*? No marine fossils occur in these gravels, and it is uncertain whether the overlying boulder-clay is the same as that which covers the gravels at Kelsea Hill. When I visited the ground many years ago I saw no reason to doubt that Mr. Wood was correct in correlating these boulder-clays. Mr. Reid, however, points out that the Hessle mammaliferous gravels occur at a much lower level than the shelly gravels—from which we may reasonably infer that they can hardly be exactly contemporaneous. But, as I shall show presently, this is really no argument against the contemporaneity of the overlying boulder-clays.

I must now give some account of this upper (or so-called 'Hessle') boulder-clay. At Hessle Cliff it is reddish brown, and quite as tough as many portions of the purple and basement-clays. The included stones are small as a rule, but fragments exceeding six inches in length are not un-

common, and now and again boulders over a foot in diameter nay be seen. Most of the stones which are of such a kind is to receive and retain striæ are well glaciated—some of he finer-grained rocks being as distinctly smoothed and cratched as any in the older boulder-clays. They have ertainly not been subjected to any rolling and abrasion ibsequent to the period of their glaciation—but the striæ e as fresh and sharp as those upon the stones of any iaracteristic till. They lie also at all angles in the unratified clay, and are scattered higgledy-piggledy through iat deposit in the usual way. Here and there, moreover, in be seen little patches of gravel and sand in the clay, of recisely the same character as those to which reference has een so frequently made in preceding descriptions of till. t one place in a quarry near Hessle railway-station I bserved boulder-clay resting directly on the chalk without he intervention of any 'Hessle gravel,' and the appearances here were highly suggestive. The colour of the clay was luller and more of a dirty brown colour, owing to the greater quantity of chalky stuff diffused through it. The chalk below vas much shattered and rose up as it were in irregular roken hummocks into the clay, the lower portion of which vas crammed with angular blocks and débris of the rock. hese were so closely set that in some places they formed uite a breccia, and one could even push one's hand into the iterstices between the blocks—appearances which are closely aralleled by the coarse débris and breccia of angular blocks hich now and again occur underneath the till in Scotland, specially when the pavement-rock is much jointed.

In the sea-cliffs the clay is well-developed, in some places ttaining a thickness of twenty and even of thirty feet. eds of gravel and sand of very variable character, and not eaching a thickness of more than a few feet, often separate from the underlying purple clay, but not infrequently these re wanting, and the red boulder-clay then rests directly on ie latter—the junction-line being often irregular. The ones are as usual small, but fragments several inches in iameter are common, and boulders, two feet across, now nd again occur. Sometimes the stones are so sparsely resent that the clay is worked for brick-making, just as is

the case with the upper boulder-clay of Lancashire, &c. There is no trace of bedding in the deposit, and nothing whatever appears from which one could infer its marine origin. Stony clays which have been deposited in water invariably present more or less well-marked stratification—the beds being often beautifully laminated. Numerous examples of such stratified stony clays occur in the glacial series (arctic shell-beds) of Scotland. One looks in vain, however, in the 'Hessle' boulder-clay for any such signs of aqueous deposition. Although not so well charged with stones as the older boulder-clays of Holderness, it is nevertheless just as tumultuous a mass as either the purple clay or the basement-clay.

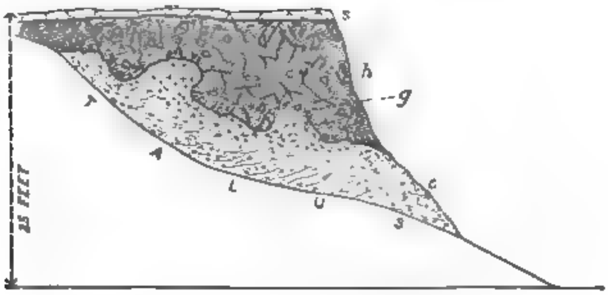

Fig. 68. Section in ballast pit, Kelsea Hill; June 1876.
s, surface soil; *h*, Hessle boulder-clay; *c*, sand and gravel, with *Corbicula fluminalis*, &c.; *g*, commingling of beds *h* and *c*.

So far, then, as an inspection of the Hessle clay goes, there are strong grounds for believing that clay to be the direct product of land-ice. This conclusion, moreover, is forced upon us when we examine more attentively the junction between the clay and the underlying Hessle gravel-beds. This was well seen, at the time of my visit, in the ballast-pit at Kelsea Hill. Here the unstratified red boulder-clay rested upon deposits of gravel and sand which were full of current-bedding. When Mr. Prestwich visited the section in 1861 this superposition of the clay does not appear to have been visible, but in 1867 Mr. Searles Wood found that the continued excavation of the 'ballast' had laid bare a most instructive section which showed the boulder-clay resting upon the stratified deposits along nearly the whole

he wide cutting. In 1876, when I examined the I saw that it had evidently been materially altered time when it was visited by Mr. Wood. All round he clay occupied the :he cutting, but it ıow and again a very junction with the ng deposits. In Fig. ıy is shown at *h*, where d a thickness of 15 ft. ıbout. It was of the ıaracter. It will be at the junction be- and the underlying s most irregular. At lay was confusedly ith the gravel. Near ction there was no bedding in the gravel, ually, as one receded clay, bedding became –the deposit being harged with the old ell, *Corbicula flumi-* d other species.

still more remarkable ena appeared on the est side of the pit ne men were at the rking. At that place xed section was very xposed (Fig. 69). As *h* represents the clay and *c* the gravel nd-beds which are full of shells. The -line it will be ob- s irregular, and at e (*g*) the till and the become commingled.

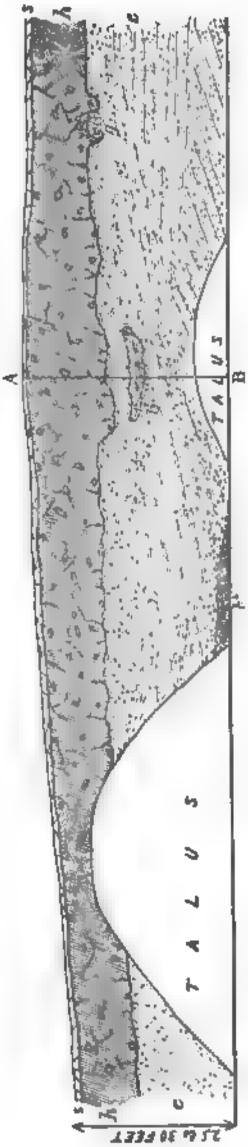

Fig. 69.—Section in pit at Kelsea Hill; June, 1876.

s, surface soil; *h*, red boulder-clay; *c*, *Corbicula*-beds; b^1, intruded mass of boulder-clay; *g*, commingling of beds *h* and *c*; b^2, boulder-clay, probably connected with *h*; *A*—*B*, line of diagram-section in Fig. 70.

At b^1 an irregular layer of boulder-clay of precisely the same character as the overlying mass makes its appearance, which I at once saw must be connected in some way with the clay at the top of the section. The gravel between the bed b^1 and the main bed h was much confused, and in fact hardly any trace of stratification was visible. All round the lower patch, indeed, the gravel was amorphous. From these and other appearances I inferred that the two beds were connected in the manner shown in the annexed diagram (Fig. 70).

Upon asking the men how they explained the occurrence of the patch at b^1, they informed me that it was only a 'leg,' and was connected with the stuff at the top—from which they said several such 'legs' had come and had given them much trouble in the working. The patch in question, then, was only a tongue of boulder-clay which had been injected or intruded under the pressure of a superincumbent ice-sheet into the *Corbicula*-beds below. Similar appearances are occasionally found in connection with the intercalated and subjacent beds of the Scottish till—tongues of till being squeezed down through and between the yielding deposits over which the subglacial mass was rolled and pressed.[1] At b^2 (Fig. 69), another apparently separate mass of boulder-clay is seen, which at first I thought must be a different bed altogether from that at the top. It was harder and tougher than the clay at h, and also of a darker and duller hue, being more of a greyish brown than a red. It closely resembled that part of the clay at Hessle Cliff which rested immediately upon the chalk. I was told, how-

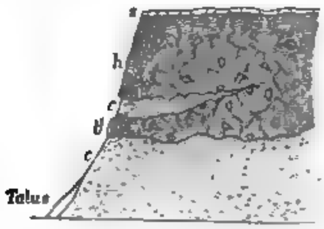

Fig. 70. Diagram section across the cutting at A B as shown in Fig. 69.

h, boulder-clay; c, *Corbicula*-beds; b^1, intruded tongue of h.

[1] In my brother's paper on the 'Phenomena of the Glacial Drift of Scotland' (*Trans. Geol. Soc. Glasg.* vol. i. part 2) will be found a section of contorted beds of sand and clay (Medwin Water) which shows a similar intercalated bed of till. This bed, my brother thought, might have been floated as a boulder, and dropped into its present position. I believe, however, that it has been injected under pressure in the manner described by the same author in his account of the till and stratified beds at Chapelhall, near Airdrie.

that it also was connected with the mass at the top. rtunately the pit face where this junction was said to been visible was quite covered up—the portion con-l by the talus being relatively wider than I have shown the sketch-section. The men assured me that at that there was no 'ballast' at all, but the clay occupied the face of the cutting from top to bottom.

'e are now in a position to consider the conclusions have been drawn from the evidence furnished by the l accumulations of East Yorkshire, so far at least as relate to the general succession of events.

he infraglacial beds at Sewerby and Speeton afford us glimpse of the conditions that obtained before the ad-of the great *mer de glace* underneath which the older l deposits of East Yorkshire were accumulated. They us, however, that before—probably long before—that leet appeared the climate was genial and fitted for the of a large mammalian fauna. At Sewerby, however, as omer, there is a break in the succession. We cannot se that boulder-clay was thrown down upon the old beach t place until long after the country had been abandoned s great pachyderms. The climate doubtless changed ally, until eventually a highly arctic molluscan fauna to occupy the bed of the North Sea. It is possible that is time, as Mr. Lamplugh suggests, the land may have relatively higher than now, and that much of the k rubble' may owe its origin to disintegration of the rock by frost. But as similar rubble is of common occur-underneath many boulder-clays, it is doubtful whether which is seen below the basement-clay of Holderness is oduct in any considerable degree of subaërial action.

e important researches of Mr. Lamplugh and the gical Survey lead to the conclusion that the base-clay and the purple clay with its associated sands and ls all belong to one and the same epoch of glaciation. g the formation of the basement-clay the bed of the Sea was occupied by a great *mer de glace* which in-Holderness from the north-east. Portions of the sea-with its arctic fauna were ploughed up and included und-moraine as the ice advanced towards the coast-

lands. From the fact that amongst the erratics Scandinavian rocks occur, as was first pointed out by Amund Helland,[1] it seems not improbable that these may have travelled all the way underneath the ice. On the other hand, we can hardly doubt that long before the appearance of the ice-sheet erratics from the Scandinavian coasts must have been sprinkled over the bed of the North Sea by ice-rafts and bergs, and it is possible therefore that some of the erratics in question may have already travelled part of their journey before they were caught up in the ground-moraine of the ice-sheet. It would seem that during this—the epoch of maximum glaciation—the higher parts of the Yorkshire moorlands and wolds peered above the surface of the invading *mer de glace* as *Nunatakkr*. These conditions must have continued for some considerable time, so as to allow of the accumulation of a thick sheet of ground-moraine, with which the sea-floor and the coast-lands were eventually overspread. Then came a time when the *mer de glace*, having reached its greatest development, began to withdraw. The purple clay, with its associated sand and gravels, is believed by Mr. Lamplugh to have been formed during this retreat of the margin of the ice from Holderness — ground-moraine and aqueous accumulations resulting from the wash of subglacial detritus forming at one and the same time in different places.

The 'basement' and 'purple' clays of Yorkshire, and the glacial accumulations of Norfolk thus tell a similar tale. Like the lower boulder-clay of Scotland, they imply the presence in the North Sea of a vast glacier or ice-sheet coming from Scandinavia, but fed by a copious discharge of ice from our own lands. Many of the characteristic erratics in the basement-clay of Holderness, as we have seen, came from the floor of the sea, and a number from Scandinavia, showing that for a long time the British ice was kept back from the North Sea basin by the superior mass that flowed outwards from the Scandinavian peninsula. In the purple clay, however, erratics of home origin are more conspicuous —pointing to the fact that as the North-Sea ice-flow dimi-

[1] *Zeitschr. deutsch. geol. Ges.* 1879, p. 67; *Archiv f. Mathem. og Naturvidensk.* 1879, p. 287. See also V. Madsen, *Quart. Journ. Geol. Soc.* vol. xlix. p. 114.

nished in bulk, glacier-masses streaming out from our own high grounds were enabled to reach the coast-lands. During the formation of the purple clay it was British ice, therefore, that formed the marginal area of the North-Sea ice-sheet in eastern Yorkshire.

Eventually the ice-sheet disappeared from the coast, and glaciers, nourished in the heights of North England, ceased to invade the low grounds. The evidence in Holderness for the succeeding changes is incomplete. The probabilities are, as we shall learn by-and-by, that after the disappearance of glacial conditions the English coasts extended considerably further seawards than is now the case. This, indeed, is suggested by the occurrence of the mammaliferous gravels underlying the boulder-clay of Hessle Cliff. If, as Mr. Wood and others have maintained, that boulder-clay be the youngest morainic accumulation of the district, it is obvious that during the formation of the underlying fresh-water deposits the land could not have been of less extent than at present, and the climate was certainly not arctic. The marine gravels of Kelsea Hill, we may suppose, were laid down at a somewhat later date, when the land had become submerged for 100 ft., or thereabout. During that submergence the Pleistocene mammalia still occupied the land —the remains found in the Kelsea gravels belonging to the same fauna as that which is met with in the gravels at Hessle Cliff. We have every reason to believe, therefore, that these beds indicate a great change of climate and a long lapse of time. It would be absurd to suppose that during the height of the preceding cold epoch—that of the maximum glaciation—England could have supported such a mammalian fauna as that of Hessle Cliff and Kelsea Hill. The very presence of the fresh-water shell *Corbicula fluminalis* in the Kelsea gravels is suggestive of great geographical and climatic changes. This mollusc could not have lived in any English river during the formation of the lower glacial deposits. It immigrated into the Humber valley after the disappearance of the great ice-sheet. Whence did it come? So far as I know, the shell occurs only in Pleistocene deposits in the east of England, and its peculiar distribution seems to suggest derivation from one and the same

source. I cannot, indeed, help suspecting that after the retreat of the great *mer de glace* the sea may have retired from the southern part of the North-Sea basin, and that the streams and the rivers of eastern England again became tributaries of the Rhine. It was probably under such conditions that *Corbicula fluminalis* and the great mammalia migrated hither. The reader will no doubt think this an extravagant suggestion to base on such slight evidence; but, as I shall show later on, it is quite in keeping with many other facts which have yet to be brought forward in their proper place.

To complete my account of the *Corbicula*-beds reference may be made to their appearance in the Fenland area. In that region they seem to be tolerably well developed (as at March), and have yielded a considerable number of marine shells, together with *Corbicula fluminalis.* The same fauna (with the exception of *Corbicula*) is present in the clays, &c., of the Nar Valley. Associated with these marine deposits of the Fenlands are certain old valley-gravels, which have yielded not only remains of the Pleistocene mammalia (as *Hippopotamus*, *Elephas antiquus*, *E. primigenius*, *Rhinoceros tichorhinus*, *Felis spelæa*, &c.), but Palæolithic implements.

We come now to the last of the glacial deposits of Holderness—the Upper or Hessle boulder-clay, which, as already shown, is clearly of glacial origin, and implies the re-appearance of a great *mer de glace* in the North Sea. This may be inferred from the fact that many of the erratics which occur in the clay have been brought down from the high grounds of England to the sea-coast, and thereafter have travelled southwards. Obviously, the British ice was unable to flow right out to sea—its progress in that direction was barred, and its course determined by the presence of another Scandinavian ice-sheet. Thus the ice that streamed out from Teesdale was deflected and compelled to flow down the coast, 'where,' as Mr. Lamplugh tells us, 'it seems to have been shouldered in, as it were, upon the land, and sometimes forced up into the open valleys of the Yorkshire coast.'

CHAPTER XXVI.

GLACIAL PHENOMENA OF ENGLAND—*continued.*

ɔial deposits of the low grounds bordering the Irish Sea—The 'lower boul-ler-clay'—The 'middle sands,' &c.—The 'upper boulder-clay'—Both ɔoulder-clays are ground-moraines—Origin of the 'middle sands'—Bone-:aves in Vale of Clwyd—Victoria Cave, near Settle—Glacial deposits of he Midlands—Mr. Deeley on the drifts of the Trent valley—Glacial deposits ›f the mountainous districts—Path of the great *mer de glace*—Conditions luring interglacial times—Ice-sheet of the 'upper boulder-clay'—Later ;laciation of Wales, Cumberland, &c.

AVING seen that the glacial succession in the eastern districts of England shows two series of boulder-clay ›osits separated by a well-marked interglacial horizon, we ıst now pass in rapid review the evidence derived from ɜ low grounds that abut upon the Irish Sea. There, as eastern England, two boulder-clays are recognised—the ver often separated from the other by a variable series of avel and sand.

The lower boulder-clay of the upland districts is more or ɜs tough and stony, and in all essential characters precisely sembles the ordinary till of the Scottish Lowlands. It is ıite unstratified, save here and there where the included ɔnes show a rude kind of arrangement, similar to that ıich has been described as not infrequently visible in the ulder-clays of eastern England. Like most deposits of e kind, it contains in places thin irregular streaks, seams, d beds of earthy sand and gravel, and interrupted bands fine gutta-percha clays, which are often crumpled, twisted, d faulted. The colour of the accumulation also varies ɔording to the nature of the rocks from which it has been rived. Thus it may be yellowish-brown, grey, dark blue, red. Its included stones are angular, subangular, blunted, ıoothed, and polished—the more compact and finer-grained ɔks having received the best 'dressing.' Moreover, they

are striated most markedly in the line of their longest diameter. In these and other respects, therefore, the lower boulder-clay of the upland districts of north-west England is obviously a characteristic ground-moraine. It rests usually upon a smoothed and striated pavement of rock, but sometimes the underlying strata are bent over, broken, crushed, and pulverised, and their débris commingled with the lower part of the boulder-clay, which in such cases is often a rather jumbled mass or rubble of blocks than a stony clay.

In Lancashire and Cheshire, below a height of 150 ft. or thereabout, this boulder-clay often contains shells and shell-fragments, which are obviously derivative.[1] Most of the shells are mere fragments, but now and again perfect specimens occur, those found in this condition being as a rule, according to Mr. T. M. Reade, such as are fitted to resist pressure or rolling about. From the lower boulder-clay of Cheshire (Dawpool) Mr. Shone records thirty-five species, of which four are Arctic and Scandinavian and seven are British boreal forms. In these low-lying tracts more or less continuous beds of gravel, sand, and clay are now and again interstratified with the boulder-clay. This shelly till, I need hardly say, frequently overlies striated rock-surfaces, or the subjacent strata may be bent over and more or less broken and jumbled.

Above it, in many places, comes a series of aqueous deposits, consisting chiefly of sand and gravel, with now and again beds of clay. This series is of very irregular thickness, reaching occasionally 200 ft. The beds have been followed at intervals from the sea-level up to heights of 1,200 ft. (Macclesfield), and even of 1,350 ft. (Moel Tryfan). Here and there they have yielded sea-shells, which are usually rather friable and much rolled. Of twenty-three species from the sands at Upton, two according to Mr. Shone are Scandinavian, and four are British boreal types. The Moel

[1] For lists of shells, &c., obtained from the glacial deposits of Lancashire and Cheshire see C. E. De Rance, 'On the Superficial Geology of the Country adjoining the Coasts of South-west Lancashire,' *Mem. Geol. Survey*; R. D. Darbyshire, *Geol. Mag.* vol. ii. p. 293; *Quart. Journ. Geol. Soc.* vol. xxx. p. 38; T. M. Reade, *ibid.* vol. xxx. p. 27; W. Shone, *ibid.* vol. xxxiv. p. 383; Nicholson, *ibid.* vol. xlviii. p. 91.

Tryfan deposits, however, have yielded nine Arctic and Scandinavian forms and eleven British types which have a high northern range.

Occupying the same relative position as these 'middle sands'—that is, intercalated between a lower and an upper boulder-clay—comes a remarkable series of deposits to which attention was called some years ago by Mr. J. D. Kendall.[1] In the district of Furness (North Lancashire) the Ulverston Mining Company sank a number of shafts and borings in search of hæmatite, and in doing so passed down through a thickness of more than a hundred feet of superficial accumulations. Mr. Kendall gives us a record of several of the borings, from which we learn that between the upper and lower boulder-clays there occurs a bed of vegetable matter, which varies from a few feet up to eight yards in thickness, and usually rests immediately upon beds of sand or clay. The upper till attains the great thickness of nearly 100 ft. while the lower till is much thinner, and does not average over 10 ft., being in some places absent. The following is one of the sections given by Mr. Kendall:—

		ft.	ins.
	Surface soil	1	0
Upper Till	Grey boulder-clay	81	0
	Blue boulder-clay	4	0
	Vegetable stratum	24	0
	Blue sand	2	0
Lower Till	Red boulder-clay	3	0
	Red boulder-clay and limestone	5	0
	Iron ore and stones	2	0
	Limestone	0	10

According to Mr. De Rance, the upper boulder-clay in the region between Ulverston and Manchester[2] closely resembles the lower shelly boulder-clay 'in its physical character, chemical composition, included erratic fragments, and the species of shells of mollusca found in it. Both clays contain more Silurian erratics in the north-west and more Carboniferous erratics in the south-east of Lancashire; both are of a dull Indian-red tint.' Here and there faint indications of bedding may sometimes be observed, and sometimes

[1] *Quart. Journ. Geol. Soc.* vol. xxxvii. p. 29.

[2] Professor Hull was the first to point out the general succession of the glacial deposits of the regions referred to above (*Mem. Lit. and Phil. Soc. Manchester*, 1865, p. 449).

the clay contains lenticular layers of sand, 'but the pebbles and boulders are embedded pell-mell and at all angles in the mass.' The base of the clay is generally a bed of 'marl,' of tolerably hard consistence; stones are not common in it, but all are much glaciated, being highly polished and intensely scratched; minute fragments of shells are common, and the clay has a deep chocolate-colour. Higher up stones are common but less glaciated, and the clay is of the usual red colour.[1] East of Blackpool the deposit has an average thickness of 30 or 40 ft. Near Ulverston, however, it reaches about 100 ft. 'Fragments and occasional perfect specimens of several shells of mollusca occur, including *Turritella terebra*, *Cardium edule*, and *Tellina balthica*.'[2]

In other places, according to the late Mr. Mackintosh,[3] the upper boulder-clay contains 'rather few stones, and exceeding few large boulders,' and is extensively used for brick-making. Where I have myself seen it, it looked not unlike the upper boulder-clay of Holderness—the stones being fewer than in the more common type of boulder-clay or till. In other places, however, the stones were more abundant, and the general appearance of the accumulation recalled that of the boulder-clays of Scotland and the north-east of England.

Mr. Mackintosh states that the upper boulder-clay 'seldom rises higher than 400 ft. or 500 ft. above the sea.' A shelly till occurs at Mottram (Manchester) at 568 ft. above the sea.

The general character of the boulder-clays of north-west England has led many geologists to uphold the view of their marine origin. It is needless to say that this conclusion was supposed to follow from the occurrence in the clays of marine shells and occasional layers and beds of sand, gravel, &c. In the last edition of this work, it was pointed out that this evidence was on all-fours with that furnished by the shelly boulder-clays of Scotland. Since the issue of that edition I have had renewed opportunities of studying the glacial deposits in question, and am still strongly convinced that the

[1] *Quart. Journ. Geol. Soc.* vol. xxvi. p. 649.
[2] *Memoirs of Geol. Surv. of England and Wales*; Explanation of Sheet 91, S.W. p. 8; see also *Op. cit.*, Explanation of Sheet 90, N.E.
[3] *Geological Magazine*, vol. ix. p. 190.

tills are the ground-moraines of ice that overflowed from the basin of the Irish Sea. The same opinion, it is needless to say, has long been held by other geologists.[1] In common with most students of glacial geology, I also formerly maintained the marine origin of all the so-called 'Middle Sands,' and therefore held that these indicated a submergence of 1,400 ft. or thereabout; but during a visit to North Wales some years ago, I found that the evidence upon which this conclusion is based was susceptible of quite another explanation; and I now agree with those who maintain that the high-level 'marine drifts' are simply re-worked morainic materials carried upwards to their present position by an ice-sheet. This view was, I think, first suggested by Mr. Goodchild and Mr. Belt, nearly twenty years ago, and more recently it has been advocated by the late Professor H. C. Lewis, Mr. P. F. Kendall, Mr. D. Bell, Professor J. F. Blake, and others.

What proportion of the 'Middle Sands' which occur at lower levels may be truly marine it is hard to say. The shells which they occasionally contain are probably, in most cases, derivative—they do not occupy the positions in which the molluscs themselves lived. Moreover, the fauna is decidedly mixed; southern forms, such as *Cytherea chione*, occurring along with boreal and common British shells. Still more remarkable is the appearance now and again of certain extinct Pliocene species, which Mr. P. F. Kendall has noted in the glacial accumulations of the Isle of Man. According to Mr. Shone, the molluscan fauna of the sands differs to some extent from that of the underlying lower boulder-clay. In the latter northern forms are common, while southern types are rare; but in the Middle Sands it is the southern forms which are most plentiful. He thinks, therefore, that the northern shells in the sands may have been derived from the lower boulder-clay. But if this be true of the northern forms, what guarantee have we that the southern types also are not derivative? Both types occur in the boulder-clay, and as the material composing the gravel- and sand-beds has certainly been in large measure obtained from the denudation and re-arrangement of boulder-clay, one

[1] Tiddeman, *Quart. Journ. Geol. Soc.* 1872, p. 486.

may well doubt whether the Middle Sands are always, or even often, of marine origin. In many places indeed they have quite the appearance of true kames.[1] Hitherto the marine origin of all those deposits has been assumed rather than proved. They must now be re-examined, however, for it is important that we should ascertain to what extent the low grounds of north-west England were submerged after the formation of the lower shelly boulder-clay. In this connection reference may be made to the exploration, under the auspices of the British Association, of Cae Gwyn Cave in the Vale of Clwyd, at a height of 400 ft. above the sea. Overlying the bone-earth of this cave, as Dr. Hicks tells us, occurred undisturbed glacial accumulations. The lower portion of these deposits, resting directly upon the bone-earth, consisted of a series of beds of laminated clay, sand, and gravel, overlaid by upper boulder-clay. A thin bed in the stratified series yielded marine shells. The fossils appear to have been chiefly fragments, but perfect shells were also obtained. The species mentioned are :—*Ostrea*, sp., *Mytilus*, sp., *Nucula nucleus*, *Cardium echinatum*, *C. edule*, *Cyprina islandica*, *Astarte borealis*, *Artemis exoleta*, *Venus gallina* (?), *Tellina balthica*, *Psammobia ferroensis*, *Donax* (?), *Mya truncata*, *Littorina*, sp., *Turritella terebra*, *Buccinum undatum*—all of which are known from the glacial series of north-west England.

Whether these shells are derivative from shelly boulder-clay, or are truly indicative of submergence, it is hard to say. If the latter be the case, they would indicate a depression of the land of 400 ft. But the most interesting fact brought to light by the exploration of this Welsh cave is the infra-glacial position of the bone-earth, which has yielded remains of the Pleistocene mammals, such as woolly rhinoceros, lion, hyæna, cave bear, red deer, reindeer, horse, &c., and flint implements. From another cave in the neighbourhood, the contents of which are obviously of the same age as those of the Cae Gwyn Cave, a similar assemblage of mammalian remains and human implements have been ob-

[1] Thus the glacial gravels described by Mr. Nicholson as occurring at a height of 900 to 1,160 ft. near Oswestry appear to be simply gravelly moraines.

tained. Mr. Davies gives the following list of species found in these caves:—

Lion	Bovine (*Bos*? *Bison*?)
Wild cat	Great Irish deer
Spotted hyæna	Red deer
Wolf	Roebuck
Fox	Reindeer
Bear	Horse
Badger	Woolly rhinoceros
Wild boar	Mammoth [1]

These cave-deposits, as we have seen, are certainly older than the upper boulder-clay, and if the shell-bed that overlies them be really a marine deposit, then they are older also than the submergence that preceded the deposition of the upper boulder-clay. We may likewise infer that they are later in date than the lower boulder-clay, for the mammalian fauna agrees in character with that which is yielded by interglacial deposits occurring on the same horizon in Scotland and the east of England.

To the same period probably belong the Pleistocene accumulations of Victoria Cave, near Settle, in Yorkshire. This cave occurs at a height of 1,450 ft. above the sea, and 900 ft. above the Ribble, which flows at the base of the hill. The bone-earth at the bottom of the cave yielded remains of hyæna, fox, badger, brown bear, grisly bear, elephant (*Elephas antiquus*), rhinoceros (*Rhinoceros leptorhinus*), hippopotamus, bison, red deer, and goat. Resting upon the deposit in which these relics occurred were certain clays that contained striated stones—accumulations undoubtedly of glacial origin.[2] Mr. Tiddeman, under whose guidance the exploration of this cave was carried on, was of opinion that the bone-earth is probably of preglacial age. It is more likely, however, to belong to the same horizon as the mammaliferous deposits of the Welsh caves.

Thus in the north-west of England we have evidence of the following succession of changes:—

1. A great *mer de glace*, coming from the basin of the Irish Sea, invades the low grounds of Lancashire and

[1] For accounts of these caves see Hicks, *Quart. Journ. Geol. Soc.* vol. xlii. p. 3; vol. xliv. p. 562; and *British Association Reports* for 1886, pp. 219, 839; 1887, pp. 301, 912.

[2] *British Association Reports*, 1873-78; *Geol. Mag.* vol. x. p. 11; *Journ. Anthrop. Inst.* 1878.

Cheshire and the Welsh borders—overspreading those regions with its bottom-moraine (lower boulder-clay).

2. The ice-sheet vanishes and a wide land-surface appears, which in time becomes well clothed with vegetation, and is occupied by man and the Pleistocene mammalia. Climate passing from arctic to temperate.

3. Submergence of the land, but to what extent is uncertain. Climate changing from cold-temperate to arctic.

4. A second *mer de glace*, coming from the same quarter as the first, overflows the low grounds as before, and clothes these with its ground-moraine (upper boulder-clay).

The glacial accumulations of the Midlands form an extremely interesting study, but have not yet been so exhaustively explored as those of the regions we have been considering. One of the most striking features they present is the plentiful occurrence of sedimentary deposits. Evidence of aqueous action is indeed so very common that most geologists who have investigated the districts in question are inclined to think that the accumulations are to a large extent of marine origin. One of the ablest and most interesting accounts of these deposits is by Mr. R. M. Deeley, who has described in great detail the phenomena met with in the basin of the Trent.[1] He shows that in that region there exist certain boulder-clays which he thinks have been laid down by glaciers flowing from the Pennine Hills,[2] while others are the products of ice coming from two directions, namely—from the west or north-west and from the east or north-east. The oldest of the glacial accumulations are two boulder-clays separated by beds of sand and gravel. These clays are so closely similar that, in the absence of the intermediate sands, &c., the one cannot be distinguished from the other. Both are crammed with rock-débris derived from the Pennine Hills. According to Mr. Deeley, the intermediate sands are of marine origin, but he admits that they contain no organic remains, and the probabilities are,

[1] *Quart. Journ. Geol. Soc.* vol. xlii. p. 437.

[2] I do not call in question Mr. Deeley's conclusions, but further evidence of local glaciation I think is desirable. If Mr. Deeley's 'Pennine boulder-clays' be really of local origin—if they point to the existence of local snow-fields and glaciers, as they would seem to do—evidences of such glaciation should be more or less strongly marked in the hills themselves, and ought therefore to be sought for.

herefore, that like similar deposits intercalated in the oulder-clays of other regions, they are really of subglacial rigin. The next boulder-clay is that known as the great halky boulder-clay, which extends from the east coast west s far as Abbots Bromley. It is underlaid here and there in ne Trent basin by beds of gravel, sand, and loam, which eem to be interstratified with the basement portion of the halky till. These beds contain in some places fragments of ea-shells, and are believed by Mr. Deeley to be marine. his kind of evidence, however, as we have seen, cannot be lied upon, and there is really nothing to show that the eposits are not of fresh-water origin.

Passing still farther westwards, beyond the Trent basin, e find that the chalky boulder-clay dies out and is replaced another boulder-clay, the materials of which have travelled om the north-west. In short, the lower boulder-clay of orth-west England and the great chalky boulder-clay of the stern counties become confluent as it were in the Midnds. From the researches of the late Mr. Mackintosh [1] d recent interesting observations by Mr. F. W. Martin,[2] we arn that before either of these two boulder-clays was posited in Central England, a considerable dispersal of elsh erratics had taken place. This, as we shall see, is uite in keeping with the appearance of Pennine morainic cumulations in the valley of the Derwent near Derby.

Thus in the Midlands we have evidence of (1) the escent of local glaciers from the Pennine Chain in the orth and from the Welsh mountains in the west; followed y (2) the advent of the North-Sea ice-sheet, which as it assed to the south-west became confluent with that broad tream of ice underneath which the lower boulder-clay of heshire, &c., was accumulated.

Overlying the chalky boulder-clay of the Midlands are reat sheets or banks of what are described by Mr. Deeley s 'deposits of stratified flinty or chalky gravel or sand.' In any places these deposits are much contorted—more specially in East Leicestershire. The deposits are freuently false-bedded, pointing to current-action sometimes

[1] *Quart. Journ. Geol. Soc.* vol. xxxv. p. 425.
[2] *Proc. Birmingham Phil. Soc.* vol. v. p. 364.

from the east or north-east and sometimes from the west. Occasionally, however, they are quite tumultuous. In the western part of the Midlands the deposits, though disturbed or even covered by later boulder-clay, often contain marine shells and shell-fragments. These are, in short, the so-called 'Middle Sands,' &c., of Cheshire, &c. All these accumulations Mr. Deeley believes to be of marine origin. But, from what has already been said when discussing the phenomena connected with the stratified deposits of Lancashire and Cheshire, it is evident that this conclusion cannot be adopted without reserve. That some degree of submergence took place after the deposition of the lower boulder-clays seems certain, but that all the stratified deposits which separate these stony clays from the succeeding glacial accumulations are of marine origin is highly improbable.

Of later date than the aqueous deposits described in the preceding paragraph, are certain gravel-beds, which Mr. Deeley believes are fluviatile. They occur in the form of terraces at various heights upon the valley-slopes, and have evidently been formed by the rivers as these cut their way down through the older boulder-clays and sands. No fresh-water shells have as yet been detected in the gravels.

'Upon these gravels, or upon the older rocks,' Mr. Deeley tells us, 'there frequently rests a boulder-clay, sometimes reaching a considerable thickness. The rock it rests upon is always much contorted or broken.' This boulder-clay is crowded with rock-fragments derived from the Pennine Chain, and is therefore, he thinks, of local origin. It is specially worthy of note that it is of later date than the old river-gravels just referred to, for it not only rests upon these in places, but follows the surface features produced during that stage of subaërial erosion.

Leaving the low grounds of England and advancing into the mountainous districts, we meet with abundant evidence to show that from all the valleys of the Lake District and of Wales there formerly issued great streams of ice which coalesced on the low grounds. For some time these local glaciers would continue to flow unimpeded by any extraneous *mer de glace*; and we may readily believe that before the advent of the latter much rock-erosion had taken place, and

quantities of débris had been carried down and piled up as moraines upon the low grounds. Some of the local moraines of this stage can still be recognised, as we have seen is the case with those of the old Pennine glaciers that deployed upon the vale of the Trent. Again, we have noted the wide dispersal of Welsh erratics over the Midlands, as evidence for the existence of great glaciers flowing east from the heights of Wales into the Severn Valley. Eventually, however, as the climax of glacial cold approached, and the ice moving outwards from the uplands of Scotland began to occupy the basin of the Solway and the Irish Sea, the ice descending from the mountains of Cumberland was impeded in its course, and forced to flow in other directions.

Many years ago Mr. Tiddeman pointed out that North Lancashire and the adjacent parts of Yorkshire and Westmoreland had been traversed by an ice-sheet—the general trend of which was towards the south or south-south-east, across deep valleys and over hills of considerable elevation. From this he justly inferred that some barrier existed in the Irish Sea by which the English ice was prevented following the slope of the ground, which is not towards south-east but south-west. That barrier was the ice deriving from the Lake Mountains. But if so, then it is obvious that some other obstruction must have existed, otherwise the glaciers of Westmoreland and Cumberland would have found for themselves a more direct route to the sea. The cause of this deflection we cannot doubt was the presence in the basin of the Irish Sea of that massive ice-sheet that streamed out from southern Scotland, reinforced as it was by ice coming from Ireland. To realise the conditions that obtained at that time we must picture to ourselves the whole basin of the Irish Sea gorged with ice. Underneath this *mer de glace* the Isle of Man was submerged—the icy current pressing forward in a general southerly direction.[1] The ice coming from the Lake District was thus, as I have said, forced aside and compelled to overflow the low grounds of Lancashire. Reaching the borders of Wales the *mer de glace* was there deflected—the major portion overflowing

[1] Cumming, *Guide to the Isle of Man*, p. 249; Horne, *Trans. Geol. Soc. Edin.* vol. ii. p. 323.

Anglesea [1] and continuing on its course towards the south, while the other smaller portion streamed across Cheshire to invade the valley of the Severn.

At the climax of this glacial epoch the Scottish ice, as Mr. Goodchild has shown,[2] ascended the valley of the Eden in Cumberland—its path being marked not only by the presence of glaciated rock-faces, but also by erratics which have come from the Southern Uplands of Scotland. These have been traced by Mr. Goodchild up to the top of Stainmoor, across which the united Scottish and Cumbrian glaciers flowed in a general easterly or north-easterly direction. The same geologist also tells us that great quantities of rock-materials derived from Scotland 'have gone over the watershed between the Eden and the South Tyne eastward to the North Sea.' I have already stated (see p. 154) that the ice which flowed down the valley of the Tweed from west to east was compelled to turn gradually away to the south-east as it neared the English border, so as to overflow Northumberland in a direction parallel to the coast-line. The Cheviot Hills appear to have been smothered in ice, for I found till with striated stones here and there on the very watershed. Nevertheless they divided the ice-flow, for all the valleys on the Scottish side are glaciated from south to north in the direction of their trend, while the English slopes of the hills are marked in the opposite direction. Here and there, however, we get evidence to show that ice passed across some of the lower heights of the dividing ridge from one country into the other, boulders from the English side being scattered over the upper reaches of one or two of the Scottish valleys.

It is obvious, then, that at the height of the glacial epoch the northern portion of the Pennine Chain was drowned in ice, which crossed the watershed on its way to the basin of the North Sea. In this manner erratics of granite and other rocks from the Lake District eventually became buried in the ground-moraines of eastern England. Farther south, however, the dominant portions of the Pennine Chain

[1] Ramsay, *Quart. Journ. Geol. Soc.* vol. xxxii. p. 116; Strahan, *ibid.* vol. xlii. p. 369.

[2] *Quart. Journ. Geol. Soc.* vol. xxxi. p. 55; *Trans. Cumberl. and Westmorel. Assoc. for the Adv. of Lit. and Science*, 1887, p. 111.

ear never to have been overtopped by ice. This is well wn by the surface features of the districts in question. ile in the northern part of the chain the hills exhibit ; flowing outline which is so characteristic of glaciated ons, in the southern districts the ground is marked by presence of sharply-edged crags and escarpments—by ; configuration, in short, which has resulted from the ;-continued action of the ordinary agents of subaërial sion and denudation. This contrast between the surface ures of the northern and southern portions of the Pennine in was pointed out long ago by my friend, Professor H. Green, who wrote to me in 1873 as follows :—'I have n much struck since I have been working on the Lower boniferous rocks of this neighbourhood [Cockermouth], he miserable character of their escarpments as compared ı those of the corresponding rocks in the centre of gland. In Derbyshire, North Staffordshire, South Lan- ıire, and South Yorkshire, the escarpments are magnificent reat craggy precipices of rock, up to fifty feet in height, ning in unbroken walls for miles, so that you could map whole country by their aid alone, without seeing a single tion. As you come northwards the escarpments grow re fragmentary, till here there is scarcely anything erving the name of an escarpment to be seen—none at on the low ground, and in exposed situations only a few ul and mostly feeble features. I have been quite staggered ıetimes to find the junction of a sandstone or limestone with underlying shales take place without any change atever in the slope of the ground. I take the meaning this to be that here the escarpments, which must once e existed, have been planed clean away by the ice- et, and that it is only in the higher grounds, where sub- al denudation acts more energetically, that they are inning to be formed afresh. But I cannot understand r it comes to pass, if the centre of England had been othed down in the same way, that there has been time that region for the subsequent formation of escarp- ıts so much larger than those hereabouts—more especi- as the rainfall is certainly greater here than farther th.' He therefore shrewdly inferred that the southern

portion of the Pennine Chain had never been overflowed by ice.

The great lobe of ice that invaded Chester pushed its way into the valley of the Severn, forcing the Welsh glaciers aside, just as the *mer de glace* that invaded England from the east thrust aside the Pennine glaciers to become confluent with the ice-flow from the Irish Sea. How far this united ice-flow extended has not yet been definitely ascertained. There can be but little doubt, however, that it occupied the whole basin of the Severn and flowed out into the Bristol Channel, where it was joined by glaciers descending from the heights of South Wales.[1] A line drawn along the foot of the Mendip Hills and the Cotteswold[2] Hills probably marks out approximately the limits reached by the ice in the Severn Valley. In the east of England the *mer de glace* reached the valley of the Thames, but the position occupied by the ice-front in the country lying between London and the north end of the Cotteswolds is somewhat uncertain. Glaciated configuration, *roches moutonnées* and striated rocks, fail us here. Instead of hard sandstones, limestones, greywacké, and igneous rocks, we meet with more or less crumbling calcareous strata, clay-beds, soft sandstones, and other semi-indurated masses, which if they had ever been glaciated, could not have retained for any lengthened time the outline impressed upon them. Moreover, the morainic materials of this region are hard to distinguish from aqueous gravels. But such appearances are characteristic, in many other countries, of deposits which have accumulated along the peripheral area of an ice-sheet. Thus, sand and gravel are always plentifully associated with the morainic materials that mark the farthest limits reached by the northern *mer de glace* of the Continent, and the same is the case in North America.

Such, then, would appear to have been the extent of glaciation in England during the formation of the lower boulder-clays. Practically the whole country as far south

[1] David, *Quart. Journ. Geol. Soc.* vol. xxxix. p. 39.

[2] Lucy, *Proc. Cotteswold Club*, April 1869, vol. vii. p. 50; E. Witchell, *ibid.* vol. vi. p. 146; Hull, *Quart. Journ. Geol. Soc.* Nov. 1866; 'Geology round Cheltenham' (*Mem. Geol. Surv.*); Phillips, *Geology of Oxford and the Valley of the Thames*; Buckland, *Reliquiæ Diluvianæ*; Belt, *Quart. Journ. Geol. Soc.* vol. xxxii. p. 80.

as the Cotteswolds and the Thames Valley was shrouded in ice, above the surface of which the Yorkshire Moors and the Derbyshire Hills peered as *Nunatakkr.* The Welsh mountains also must have raised their summits considerably above the general level of the *mer de glace.*

Next came the retreat of the ice-sheet. The evidence derived from a study of the interglacial deposits of Lancashire, &c., and of Yorkshire, shows that the disappearance of the ice was followed, not by submergence, but by land-conditions and a temperate climate. The glacial phenomena of the Midlands are in keeping with this conclusion, for the sand and gravel which form so marked a feature of that district cannot be shown to be of marine origin. They are simply the deposits laid down by torrential waters during the melting of the ice. It is by no means improbable, however, that when the *mer de glace* was in full retreat, the low-lying tracts of Central England may have been for some time submerged. For, as the late Mr. Carvill Lewis pointed out,[1] the rivers draining that region must have been ponded back by the *mer de glace* when the ice-front had retired to the coast-lands. During its advance, indeed, the same results must have followed; so that both before and after the glacial invasion of the Midlands wide areas in the low grounds would be converted into broad glacial lakes. When these lakes were drained by the final disappearance of the North-Sea ice, the Trent and its tributaries were free to begin their work of erosion and redistribution of superficial accumulations. To this stage apparently belong the old river-terraces described by Mr. Deeley.

The evidence supplied by the interglacial deposits of the maritime tracts leads to the conclusion that partial submergence next ensued—but to what extent is quite uncertain. Probably it did not exceed 300 or 400 ft., and it may not have been so much—for the evidence of the shelly sands ('Middle Sands') is not to be relied upon. But with this submergence—however great or small it may have been—the climate became colder, and snow-fields and glaciers reappeared in Wales, the Lake Country, and the Pennine Chain. For some time, doubtless, these glaciers would be

[1] *Glacial Geology of Great Britain and Ireland*, p. 42.

independent, and flow freely outwards in all directions to the low grounds. Eventually, however, their course was interrupted in the same way as that of their predecessors had been, and another great ice-sheet occupied the basin of the Irish Sea, and invaded the maritime tracts of the north-west. But this second invasion from the sea was not on the same scale as that of the earlier period. The ice was deflected as before by the Welsh mountains—a long tongue from the *mer de glace* of the Irish Sea being protruded across Cheshire into Staffordshire, where it would seem to have come into touch with glaciers flowing from the Pennine Hills. The low grounds watered by the Trent, however, were not again invaded by the North-Sea *mer de glace*, which at this time would appear not to have extended farther west than the Valley of the Humber and the Lincoln Wolds. From the Derbyshire Hills local glaciers were therefore free to creep out upon the low grounds and, following the lines of interglacial erosion, according to Mr. Deeley, they spread their moraines over interglacial river-gravels.

We have now traced the history of the Lower and Upper Boulder-clays of the low-lying tracts of England, and must next glance at the evidence of glacial action in the hilly districts. The dissolution of the later *mer de glace* (that of the Upper Boulder-clay) must have taken some time. Probably its motion was gradually arrested in many places. As the ice-front withdrew from the maritime tracts torrential waters derived from it and the adjacent high-grounds distributed gravel and sand in many places, giving rise to deposits which are comparable to the similar accumulations met with at all levels in the lowland tracts of Scotland. Rock-débris and erratics included in the ice would be dropped here and there as that melted away, while in other places the same materials would be rolled forward and re-distributed by streams and torrents. Again, temporary glacial lakes might well be formed in certain regions and become the receptacles of much clay, sand, and gravel. In this manner we may account for the long banks, mounds, and sheets of sedimentary materials which in many places are scattered over the surface of the Upper Boulder-clay.

In discussing the glacial succession in Scotland I have

ven some reasons for believing that after the final retreat : the later *mer de glace* a wide land-surface obtained under mperate conditions of climate. If that be true for Scotnd it must be equally true for England, but I shall postpne consideration of this question until we have reviewed the ridence for the glacial succession in Northern Europe. At resent we may freely admit that no interglacial beds of later ite than the Upper Boulder-clay have been recognised in ngland. We have evidence, however, of a notable recruescence of glacial action posterior to the disappearance of e later *mer de glace*.

Sir Andrew Ramsay, who was intimately familiar with e glacial phenomena of Wales, long ago pointed out that e older morainic accumulations of that region had been oughed out by a series of later glaciers, some of which tained a very large size. In common with other geologists, believed that there had been two periods of glaciation, parated by an epoch of submergence, during which Wales is drowned to a depth of some 1,400 ft. or more. The ulder-clays, which extend from the low grounds into the ountain-valleys, and sweep up to heights of over 2,000 ft., ere at first supposed by Ramsay to be of marine origin, it he clearly distinguished between them and the valleyoraines. The former he described as presenting a smooth id broadly undulating surface, which might be followed om the low grounds into the wide recesses of many of the ountain-valleys. The ploughing out of this 'drift,' he tells s, is seen on a large scale in the Passes of Nant Francon id Llanberis. One cannot, indeed, read what Ramsay has ritten concerning the glaciation of Wales without noting iat he had clearly perceived that the lake-basins and rminal moraines were the work of independent glaciers hich came into existence after the deposition of the oulder-clay. He has specially referred to the large local acier of Nant Francon, which descended the valley of the gwen and deposited the well-marked moraines on which enrhyn Castle stands. The action of this and other glaciers scending from the Snowdonian mountains has probably, his opinion, obliterated traces of the earlier glaciation fected by the *mer de glace* that overflowed Anglesea from

north-east.[1] From what I have myself seen of the glacial phenomena of North Wales, I believe we have there precisely the same phenomena as are met with in the Highlands and Uplands of Scotland. The last large glaciers of the Principality belong to a distinct stage or epoch of the Ice Age, separated from the epoch of the Upper Boulder-clay by a protracted period of time. It was under similar conditions, as I believe, that the moraines and morainic gravels of the northern Lake District were formed. In this region, however, the terminal moraines in the lower reaches of the valleys are seldom so conspicuous as those of North Wales. It is only towards the heads of the valleys that lateral and terminal moraines have preserved much of their original form. The same is to a large extent true also of the moraines of the Welsh mountain-valleys—those at the lower ends of the larger lakes being more denuded and washed down than the very perfect moraines that occur near the heads of the valleys and in cirques. In the previous edition of this work I distinguished between these two sets of valley-moraines, but I had not then perceived the meaning of the older and larger series. 'The terminal moraines of the latest glaciers,' I remarked, 'are restricted to the higher mountain-valleys, and even in many cases to the upper reaches of these; but much farther down the valleys, and at levels on the hill-slopes which the latest local glaciers never attained, great masses of true moraine-matter exist.' These great moraines I then believed were laid down during the retreat of the later *mer de glace*—that, namely, of the Upper Boulder-clay—when it had become resolved, as it were, into 'a series of gigantic local glaciers'—a view which can no longer be supported.

The disappearance of these large valley-glaciers was marked by the deposition of sheets of morainic débris and gravel, and by the stranding of numerous perched blocks on the slopes of the mountains. There is no evidence either in North Wales or the Lake District that would lead us at once to infer that the small and often very perfect moraines at the heads of the valleys belong to a much later stage of glacial times. We might suppose that these smaller moraines

[1] 'The Geology of North Wales,' *Mem. Geol. Survey*, p. 272. See also *The Old Glaciers of Switzerland and North Wales.*

simply mark a final pause in the retreat of the great glaciers. But in Scotland, as we have seen, the evidence is much clearer—for in that region the 50-ft. beach is intercalated between the two sets of moraines. A long period of temperate conditions therefore intervened between the disappearance of the larger glaciers and the advent of their comparatively diminutive successors; and we may reasonably infer that the two sets of valley-moraines in North Wales and the Lake District tell a similar tale.

CHAPTER XXVII.

DRIFT DEPOSITS OF SOUTHERN ENGLAND, AND SO-CALLED 'POSTGLACIAL BEDS.'

Physical conditions in extra-glacial tracts—Action of frost and thaw in Arctic regions—Rubble-drift; 'Head;' Coombe-rock—'Trail' and other evidence of superficial disturbance—Mr. Spurrell's observations on 'underplight,' &c.—Movements of soil and rock-débris—Small ice-caps and beds of frozen snow—Erratics in old beach of Sussex coast; interglacial beds above; rubble-drift overlying the latter—So-called 'postglacial' beds—Lower buried forest and peat—Marine and estuarine deposits—Upper forest-bed and peat.

BEFORE we proceed to sum up the general results of our survey of the glacial accumulations of England and Wales, we must consider the appearances presented by those parts of the country which seem never to have been invaded by the great *mer de glace*. During the epoch of maximum glaciation, the inland ice advanced no farther south than the valley of the Thames. The non-glaciated areas of Southern England, however, did not escape the influence of severe climatic conditions. When all the regions lying to the north were swathed in perennial snow and ice, it is not to be supposed that the non-glaciated districts were clothed with much vegetation. In Arctic countries it is true that the low grounds bordering on the sea show a more or less thick carpeting of plants when the winter snows have vanished. But those high latitudes are favoured with months of continuous daylight and a warm sun. In our latitude, however, no such genial summer conditions could obtain. The enormous accumulations of ice which covered so large a portion of our region denote cloudy skies and a copious snowfall. Much of Southern England itself must have been buried in snow throughout the winter, and when summer returned hill-slopes and low grounds alike must

have been subjected to the denuding action of torrential water. Immediately south of the northern ice-sheet, indeed, deep snow covering large tracts of country may have endured often for years, notwithstanding the melting that must have taken place in summer. Everyone has noticed that in winter and early spring our streams and rivers are usually muddier than in summer and autumn, when they are swollen by heavy rain. The muddier water-flow is of course due to the action of frost, by means of which rocks are disintegrated and soils are broken up and pulverised, so that when thaw supervenes the superficial covering becomes soaked with moisture like a sponge. To such an extent does this take place, that one may often see the saturated soil creeping, slipping, and even flowing down the slopes. The effect of mere thaw is necessarily much intensified when the water derived from melting snows is present. Rills and tiny brooks then become converted into dark muddy torrents, and great quantities of fine-grained detritus are eventually swept into the rivers.[1] If action of this kind is possible under the mild conditions of climate which we enjoy, it may readily be believed that similar but much more vigorous action must take place in Arctic regions. Sir Edward Belcher makes special reference to the 'flowing soils' of Buckingham Island, one of the Victoria Archipelago, in lat. 77° N. He ascended a hill 200 ft. above the sea to make observations, and found the soil well frozen and firm and covered with a slight crust of snow. But as the power of the sun increased towards noon, the snow disappeared, and the legs of his instrument sank deeper in the ground, the levels requiring frequent adjustment. Yet the temperature of the air was low, for a protected thermometer indicated 7° below freezing. 'As noon passed,' Sir Edward tells us, 'the soil in all the hollows or small watercourses became semi-fluid, and very uncomfortable to walk on or sink into. At the edge of the southern bank the mud could be seen actually *flowing*; reminding one more of an asphalt bank in a tropical region than our position in 77° 10′ N., and, when a mist too deeply enshrouded the sun, attended with anything but pleasurable feelings. The entire aspect of our immediate position, and

[1] J. Geikie, *Address to the Geol. Soc. Edin.* 1884.

beneath, presented the features of a newly-drained lake, the lower land conveying its fluid mud to the sea. The soil, a dark brown ferruginous clay, resulting from the disintegration of clay-ironstone, black and glazed by exposure to the sun, and cracking into compartments, impressed on my mind the probability that a continued series of hot days would materially change the outlines of my present position, converting it possibly into a similar slope to that exhibited beneath. . . . About 2 P.M. I was not at all sorry to commence our descent, but we experienced very dirty work before this was effected. The entire slope, in consequence of the thaw, had become a fluid moving *chute* of *débris* for at least one foot in depth.' [1]

We gather also from the experiences of Arctic travellers that in summer temporary lakes are often formed behind banks and barriers of snow, which now and again give way and allow the lakes to become suddenly drained. In this way destructive *débâcles* are produced. Dr. Sutherland, who visited Melville Island in 1851, has given some account of these. He tells us how on one occasion 'a chain of small lakes burst open, and rushing with great violence along the hitherto almost dry watercourse, tearing up masses of rock, and bearing down a burden of white mud, set free among the rolling stones at the bottom, they spread their contents over the whole of the (ice-covered) harbour.' On visiting the lakes from which this *débâcle* had come, Dr. Sutherland found that blocks of ice seven to eight feet thick had been floated by the water and stranded at heights considerably above the usual level of the lakes. 'It was wonderful to see the deep impressions that had been made in the gravel composing the bottom and borders of the lakes by the force with which the ice had been driven against it.' [2]

It is unnecessary to cite from the records of Arctic travel evidence of the disrupting action of frost, reference having already been made to this subject (see p. 40). One can hardly doubt that in glacial times Southern England must have experienced the effects of severe frosts. It is not at

[1] *The Last of the Arctic Voyages*, vol. i. p. 306.
[2] *Journal of a Voyage in Baffin's Bay and Barrow Straits*, vol. ii. pp. 199-201.

all improbable, indeed, that here and there the higher grounds might even be invested with local ice-caps like those described by Payer as covering the low-lying islets off the coast of Franz-Josef Land; while in the valleys drifted snows might sometimes accumulate to such depths as to remain for years. But much of the snow-covering would doubtless melt in spring and summer, and hence we might expect to meet with more or less abundant evidence in Southern England of the action of frost and thaw, as shown in ruptured rock-surfaces, accumulations of rock-débris, coarse gravels, tumbled and confused subsoils, and sheets of sand, loam, and brick-earth.

One of the most interesting of the superficial deposits encountered in the region under review is that known by the general name of 'rubble-drift.' It appears to be widely distributed, occurring at all heights close down to the sea-level. In Devon and Cornwall it is well exposed at many places on the coast, where it caps the cliffs, and is known as 'head.' This 'head' consists of a more or less coarse agglomeration of angular débris and large blocks set in an earthy matrix. Occasionally it shows a kind of rude bedding, but not such as would suggest arrangement by running water. As a rule it is unfossiliferous, but now and again land and fresh-water shells may be met with. The stones and blocks are all of local origin, and have generally not travelled far. Mr. Godwin-Austen would appear to have been the first to recognise the connection of this 'head' with the glacial period. He was of opinion that it had resulted from long-continued subaërial waste under severe climatic conditions, such as must have obtained if the land had formerly been considerably elevated. Others have attributed the origin of the 'head' to heavy rain, to *débâcles*, to river-action, and to the sea. But nearly all admit that ice in some form or other has aided in the formation of the deposit. I shall not attempt to discuss these various views, but reference may be made to the marine hypothesis which has recently been advocated by Mr. Prestwich,[1] who thinks

[1] *Quart. Journ. Geol. Soc.* vol. xlviii. p. 322. This paper gives an outline of the various views which have been advanced in explanation of the 'head' and other 'rubble-drifts.' See paper by the same author in *Phil. Trans.* 1893, A. p. 903.

that 'head' and other similar rubble-drifts have been swept down from higher to lower levels during the emergence of the land from an imagined subsidence of 1,000 ft. under the sea. He thinks that when re-elevation ensued, the movement would proceed by fits and starts, so that divergent currents would be set in motion from each drowned hill or group of hills as the crust was jerked upwards. When the currents were rapid, the materials swept downward would be coarse; when the motion was more gentle, the drifted materials would be finer-grained. This hypothesis, I fear, is more ingenious than convincing. After all, none of the deposits shows any trace of a marine origin, and we are hardly entitled to assume a depression of the land without some direct and unequivocal evidence of the former presence of the sea.

Mr. Ussher, who is intimately acquainted with the superficial accumulations of the south-west, follows Mr. Godwin-Austen's lead, and holds that 'head' is largely the product of great subaërial waste; but he thinks that torrential surface-waters and melting snows had much to do with the distribution of the materials.[1] It is interesting to note that in Cornwall, where the 'head' is well developed, there occur, underneath certain postglacial deposits, coarse torrential gravels, which are well known from the fact that they have been long worked to get at the lumps of tin-ore which they contain. This tin-bearing accumulation is composed of a confused mass of sand, gravel, pebbles, blocks, and boulders. It is just such a deposit as might have been formed by torrents more or less suddenly discharged from melting snow and ice. Mr. Ussher has shown that it is posterior in age to certain raised beaches upon which the 'head' reposes, and is therefore approximately of the same age as the 'head' itself. The latter, in short, represents the angular débris moved forward by the action of frost, melting snows and thawing subsoils, while the stanniferous gravels denote that portion of the subaërial waste which was swept into gullies and stream-courses, and hurried along by the tumultuous waters of spring and summer.

Views similar to those held by Mr. Ussher as to the origin

[1] *The Post-Tertiary Geology of Cornwall*, p. 42.

'head' have been advanced by Mr. Reid,[1] in explana-
›f another variety of rubble-drift, known as 'coombe-
which extends from the slopes of the South Downs for
eight miles over the adjacent low grounds. 'In the
bes, and for three or four miles south of the Downs, it
ts,' Mr. Reid says, 'of a mass of unstratified or ob-
y stratified flints, battered but not rolled, and embedded
natrix of chalky paste and pieces of chalk.' Farther
it passes laterally into an accumulation of flints in a
matrix, and eventually, as at Selsey, the deposit
es into almost clean brick-earth, with scattered angular
Teeth of elephant and horse, broken and apparently
ed before they were embedded, and a few Palæolithic
nents, have been obtained from this brick-earth.[2] The
be-rock,' according to Mr. Reid, has been formed under
climatic conditions—at a time when all rocks not
ted by snow were permanently frozen to a great depth.
such conditions, the chalk of the Downs would be
cally impervious, and the whole rainfall, instead of
g into the ground and being slowly given out again in
s, as at present, 'would immediately run off any steep
like those of the Downs, and form transitory moun-
orrents. These would tear up a layer of rubble pre-
y loosened by the frost and unprotected by vegetation.'
in this way, as Mr. Reid believes, that the flat lands
en the Downs and the sea were covered with subaërial
which, as they advanced, eventually became confluent
he whole plain—the materials becoming finer-grained
rther they were carried. This explanation, it will be
ed, is quite in keeping with existing phenomena in
regions, and had already been advanced by other
ers to account for similar appearances in extra-glacial

. J. Allen Brown has called attention to the peculiar form of the flint
nts which have been met with in the 'rubble-drifts' of Southern
l. According to him they are intermediate in form between the rudely-
flints of the old river-gravels of the Thames, &c. (to be referred to in
el) and the implements that are classed in this country as of Neolithic
nese intermediate forms he terms 'Mesolithic.' See *Journ. Anthrop.*
. xxii. p. 66.
art. Journ. Geol. Soc. vol. xliii. p. 364.
yden, *Geol. and Geogr. Survey of Colorado*, 1873, p. 46; W. C. Kerr,
ol. Surv. N. Carolina, vol. i. (1875) p. 156; Ramsay and J. Geikie,

Rubble-drift, overlying raised beaches, likewise occur in Guernsey, where they have been carefully studied by Mr. A. Collenette.[1] Shelves and platforms of rock, covered with beach-gravels, and now and again backed by sea-worn caves, occur at many places all round the island at an elevation of 25 ft. above the sea. This old sea-margin is more or less obscured under a confused mass of broken rock or rubble. Mr. Collenette points out that the fragments are all angular and not at all water-worn. 'They do not,' he says, 'show a sign of lichen-growth or any weathering other than the splitting effect of cold, hence must have fallen into position at the base of the cliff-heads when the rock-platform was above the action of the sea.' He holds, therefore, that during the formation of the rock-rubble the sea had retreated to a lower level. After this epoch of land-elevation, the island, he thinks, was probably completely submerged—certain clays which occur throughout the island being, according to him, of marine origin. He does not, however, cite the occurrence of any marine organic remains, and some doubt must therefore attach to this interpretation of the evidence. Re-elevation succeeded this submergence—the retreat of the sea being marked by pauses, during which beaches were formed at 65 ft. and 51 ft. respectively above the present sea-level.

There are certain other accumulations, however, of common occurrence in Southern England, which require some further interpretation. I refer to the disturbed, confused, and contorted deposits which Mr. Fisher has described under the name of 'Trail,'[2] and which have more recently been studied by Mr. F. C. J. Spurrell.[3] In many places the superficial clays, sands, and gravels show curious flexures and foldings and other disturbed appearances, which recall the somewhat similar phenomena not infrequently seen in deposits that occur within truly glaciated areas. Mr. Fisher attributed the disturbances in question to the action of land-

Quart. Journ. Geol. Soc. vol. xxxiv. (1878) p. 515; *Prehistoric Europe*, pp. 163, 216–230. See also *Quart. Journ. Geol. Soc.* vol. xxxvii. (1882) p. 718, where Mr. S. V. Wood attributes the origin of such accumulations to action of frost and thaw.

[1] *Trans. Guernsey Soc. Nat. Science*, 1892; *The Sun*, Guernsey, Dec. 16, 1893.

[2] *Quart. Journ. Geol. Soc.* vol. xxii. p. 533; *Geol. Mag.* vol. iv. p. 193.

[3] *Report of West Kent Nat. Hist. Soc.* 1886.

ice, and this view is to some extent adopted by Mr. Spurrell, but with some important modifications. The term 'trail' he restricts to the confused materials that lie in the troughs and hollows of the foldings, while 'underplight' is the name given to the folds themselves. The rocks and beds that form the folds and sides of the hollows, he tells us, have been pinched, crumpled, and squeezed into sheets and ribbons which, still retaining their connection with the parent rock, occasionally project into the 'trail.' The puckering and flexing, according to him, are the result of the mechanical movement of ice or of thawing soil, while 'trail' is the rearrangement of the detached and comminuted rocks after the ice had melted. In support of this view he refers to the fact that underneath the heavy snows of Arctic regions the soil retains a temperature many degrees higher than that of the external atmosphere. Thus, long before the overlying snow has vanished, the soil is softened and rendered liable to displacement under the weight of its covering. Mr. Spurrell also cites Sir E. Belcher's description of the flowing muds of Arctic lands in explanation of 'underplight' and 'trail.' Thus, according to him, these curious phenomena 'may have resulted from the heavy pressure of a superincumbent mass of snow on a soil in a condition capable of yielding,' or they may owe their origin to 'the intermittent flowing, by its own weight, of a soil undergoing a thaw.' It is particularly noteworthy that the movement of the superficial materials has always been down-hill—the undulations, wrinkles, ridges, and folds produced by the movement invariably extending at right angles to the inclination of the surface. Some of these folds attain a considerable size. Thus, at Erith, one was traced for over fifty yards. Mr. Spurrell also mentions the occurrence in certain valleys of lengthened longitudinal ridges of gravel which have apparently been formed by the descent of sliding masses from the adjacent hill-slopes. Usually, however, they are much smaller. Frequently the flexures and folds are nearly upright, and when this is the case they are most numerous and more or less perfect. On steeper ground they approach the horizontal, and often incline downwards, so that they are less easy to trace. When the inclination of the surface is great, the folds

and creases become so long drawn out and flattened that they cease to be recognisable as flexures, and then simulate the appearance of water-arranged layers. From these facts and other evidence Mr. Spurrell concludes that the contortions of 'underplight' 'are the result of steady movement, a flow or push in certain directions in accordance with the slopes on the surface of the land, the amount of slope determining the direction being often very slight.' The late Mr. S. V. Wood, some years ago (1882), attributed the earthy rubble-drifts of the non-glaciated areas to the flowing of the soil—the 'rubble' being the result of hard frosts acting on exposed rock-surfaces. The disturbed appearances described by Mr. Fisher as 'trail,' which are seen in certain old beaches on the south coast of England, Mr. Wood thought might have been caused by the grounding of pack-ice, or by the burying of masses of floe-ice under subsequently deposited mud and loam. The thawing of such buried masses after cold conditions had passed away would let down the mud and loam, and thus cause an appearance of confusion. But as 'trail' and 'underplight' occur at all levels in the interior of the extra-glacial tracts, this explanation cannot be sustained.

'Trail' and 'underplight' are overlaid by 'rain-warp'—the result of the later action of rain. This deposit consists of the finer ingredients separated from the 'trail'—the coarser materials being left behind as surface-gravel. Rain-warp is generally a yellow, brown, or red loam, and is commonly met with immediately underneath the vegetable soil. Neither in 'trail' nor in 'rain-warp' is there the slightest evidence of marine action. They are both obviously of terrestrial origin. Under the influence of melting snow and ice and the thawing of the soil, the flat lands in the districts described by Mr. Spurrell (West Kent, &c.) became covered with a deep layer of sludge and confused gravel—the latter often accumulating in great sheets in the vicinity of rivers, where it was liable to become modified by water-action. Here and there considerable erosion seems to have been effected by snow and ice—large fragments of hard Greensand and Wealden rocks having been dislodged and moved away. Masses of pebble-beds, perhaps frozen solid at the time, have

been removed *en bloc*, and 'where the edges of the masses grated against each other the pebbles are splintered.' At Swanscombe Mr. Spurrell saw an instance 'of the passage of a mass of stones over a large flint block in the chalk, too large to move, from which two passing stones had separated flakes, each stone carrying away a flake with it to distances of 18 and 6 inches respectively before the movement was arrested.' In regions outside of the chalk area the evidences of land-spoil are equally conspicuous. Thus, in the Weald under the Greensand escarpment occur broad and thick accumulations of a kind of stony clay, from which surface weathering has removed the finer materials, leaving thick layers of angular and half-worn fragments of rocks and pebbles. Many of the smaller valleys between Maidstone and Westerham are crowded with masses of confused materials which are evidently of the nature of 'trail.'

Besides the layers or coverings of 'trail' and 'underplight' which are everywhere conspicuous at the surface, Mr. Spurrell has met with evidence of earlier phenomena of the same kind. For an account of this evidence the reader is referred to Mr. Spurrell's paper itself.[1] It may suffice to state here that in several sections two and sometimes three layers of trail occur, separated by variable thicknesses of rain-warp, brick-earth, &c. Many facts, moreover, point to great denudation, or wearing away of the land-surface, having taken place between the accumulation of two successive layers of 'trail.' In short, a consideration of the evidence adduced leads to the conclusion that subaërial erosion of the surface has been very considerable, and that the work of denudation has been repeated at more or less widely separated intervals.

Before leaving Mr. Spurrell's interesting work reference may be made to his acute suggestion as to the origin or deepening of the dry valleys of the chalk area. He points out that they cannot owe their origin entirely to the dissolution of the rock by chemical agency, otherwise their

[1] The reader may note here that 'trail' and 'underplight' occur again and again in the valley of the Thames, affecting the 'river drifts,' in which relics of Palæolithic man and the extinct or no longer indigenous mammals are met with. The geological position of those 'river-drifts' and their relation to the glacial accumulations will be considered in Chapter XXXVII.

bottoms ought to be more or less deeply covered with the insoluble residue of the chalk—clay and flints—which, however, are absent. Neither could the valleys have been excavated under existing conditions by superficial streams, for the chalk absorbs rain and superficial water like a sponge. During glacial times, however, the ground would be frozen and impervious, and the 'ice-laden and tumultuous floods of summer would have a scouring power even greater than water.'[1] He thinks that the 'glaciation' was not merely annual or seasonal, but sometimes continuous for a lengthened period, and that if true glaciers did not occupy the valleys, these must yet in some places have been choked with ice and chalk débris. He refers to instances where it was evident that the rock forming the valley-slopes had been subjected to great pressure. Thus, in one place the chalk had been crushed and moved over itself, leaving spaces between the blocks, while the included layers of flints had been pulverised. These appearances were visible in a pit to a depth of twenty feet.

Geologists generally hesitate to attribute any of the superficial deposits of Southern England to true glacial action. Neither rock-striæ, *roches moutonnées*, nor recognisable moraines occur, and we may reasonably conclude, therefore, that local valley-glaciers, comparable to those which formerly existed in Wales and the North, were unknown in Southern England. Nevertheless, it is by no means improbable that here and there local ice-caps may have crowned some of the heights—creeping out in all directions down the slopes, and not necessarily forming valley-glaciers. Such ice-caps are described by Payer as occurring in Franz-Josef Land. 'The smaller islands,' he says, 'are covered with glaciers with low rounded tops, so that a section through them would present a regular defined segment of a circle; hence many streams descending from the summits of the plateaux spread themselves over the mountain-slopes, and need not be concentrated in valleys and hollows in order to become glaciers.'[2] Colonel Godwin-Austen has also described

[1] Mr. Clement Reid, in a paper already cited (*Quart. Journ. Geol. Soc.* 1887, p. 364), had independently arrived at the same conclusions as Mr. Spurrell with regard to the origin of dry chalk valleys.

[2] *New Lands within the Arctic Circle*, vol. ii. p. 84. Possibly some of the so-called 'terminal curvature' described by Mr. Mackintosh as occurring among

the occurrence of 'patches of ice, many square acres in extent, that are to be seen at the present day on the wide level plateaux of the Chang Chingmo in Thibet—that is to say, solid ice not more than 20 ft. thick, with a flat but much broken surface, and with a wall-like margin in most places.' These he noticed lasted until the winter snows began again, and in very warm summers, he thinks, they may almost entirely disappear. 'A very slight lowering of the temperature would soon cause these thin ice-sheets to thicken and extend on all sides. Such,' he conceives, 'was very much the state of all our high grounds in the South of England,' during the Glacial Period. Frozen snow-beds of this kind, he thinks, would modify the surface of the country, 'wearing it down to the even beautiful curves it now presents, and distributing the waste over the adjacent lands.' The same author refers to the obstruction of drainage which would sometimes result from the choking of valleys, causing rivers in summer to scatter their detritus over regions which they could not otherwise reach. This view was suggested to me in 1876 by Mr. Darwin [1] to account for the distribution of the coarse tumultuous gravels which are so often sprinkled over hill and valley alike in the south of England. Amongst these one frequently sees sand, clay, grit, rounded stones, angular blocks, and sharp-edged débris, all huddled together in dire confusion—the larger stones often standing on end, and not lying in the position they must have assumed under ordinary river-action. Mr. Darwin thought that great beds of frozen snow might have accumulated in the manner already described, and that many valleys in Southern England might thus have been filled to considerable depths, during a large

the Quantocks and in Exmoor, and the 'evidences of glacial action' noted by Mr. E. Vivian, Mr. C. Spence Bate, and Mr. R. N. Worth in various parts of Devon, may be due to little ice-caps and sheets of frozen snow. By terminal curvature is meant the bending-over of the outcropping edges of strata. Such curvature is a common feature in glaciated regions, but it also occurs in a less pronounced degree on hill-slopes which have certainly never been glaciated. In the latter case it is simply the result of ordinary subaërial action, including frost, by which the division-planes of the strata are widened, movement taking place in the line of least resistance, or down-hill. Hence the beds are curved or bent over in the direction of the slope. See Mackintosh, *Quart. Journ. Geol. Soc.* vol. xxiii. p. 326; Ussher, *ibid.* vol. xxxiv. p. 49; Vivian, *Trans. Devon. Assoc.* 1868, p. 357; Bate, *ibid.* 1871, p. 517; Worth, *ibid.* 1881, p. 351.

[1] *Prehistoric Europe*, p. 141; *Life and Letters of Charles Darwin*, vol. iii p. 213.

part of the year, with blown snow afterwards congealed. In autumn, when running water failed, the lines of drainage might in many cases be more or less choked, and it would be a mere chance whether the drainage, together with detritus, would follow the same lines during the succeeding summer. Such action being repeated year after year, many valleys might be largely filled up with rudely alternating layers and sheets of frozen snow or ice and fluviatile detritus. In this way we may readily understand how drainage-systems might be so much deranged as to enable the swollen rivers in summer to reach great heights, and even to overflow the hills and plateaux between adjacent valleys. When the climate became warmer, the buried sheets of frozen snow and ice would melt slowly away, and the included detritus would then be let down so gradually, that elongated stones would usually arrange themselves in lines of least resistance. The differential movement of the slowly subsiding rubble and loam would, in short, tend to make the stones stand on end. These suggestions of Mr. Darwin are not mere plausible conjectures. In the north of Alaska, extensive sheets of ice and frozen soils occur. Nor can there be much doubt that these date back to Pleistocene times, seeing that the frozen soils contain remains of the mammoth and other contemporaneous mammals. Similar frozen soils have long been known in Siberia, and to these I shall refer in the sequel. Here, then, we have direct proof of the fact of frozen snow and ice having accumulated in the hollows of the land in extra-glacial regions.

Probably all the various actions now referred to have operated in Southern England at some time or other during the several glacial stages of the Ice Age, and we need not be surprised therefore at the changeable aspect of the superficial accumulations, which in these districts are the equivalents of the morainic deposits of the North. During the climax of glacial cold it is unlikely that Southern England had much if any vegetation to boast of, and it is very doubtful indeed whether the country was then inhabited by either reindeer, musk-ox, or other mammal. It is certain, however, that it was clothed and peopled by an Arctic flora and fauna when the climatic conditions were somewhat less

severe, relics of that flora having been detected at Bovey Tracey,[1] while remains of reindeer, musk-ox, and other northern animals have frequently been encountered in the superficial drifts.

I have referred to certain observations by Mr. Spurrell which seem to indicate that Southern England has been subjected to more than one period of severe climatic conditions. This is what might have been expected, for, if cold and temperate epochs alternated in the North, the South must have experienced similar changes. But much clearer evidence, bearing directly on the question of climatic mutations, has recently been adduced by Mr. Clement Reid.[2] It has long been known that erratics of granite, diorite, and other rocks occur associated with Pleistocene deposits at Pagham, on the Sussex coast, to which place they must have been carried by floating ice. An exhaustive examination of the coast between Brighton and Selsey Bill has enabled Mr. Reid to show that the erratics in question are derivative from a deposit which was fortunately exposed in place by the action of the sea during the stormy autumn of 1891. The deposit was made up of coarse gravel with small and large erratics, varying in size from one foot or so to upwards of eight feet in diameter, and rested on a surface of hard Tertiary clays, which had obviously formed an old beach. Many of the erratics had been forcibly pressed or screwed into the clay until their upper surface was flush with the general level of the gently inclined platform. In this process the more yielding rocks had been crushed and splintered. The surface of the clay showed besides numerous pits, which had not been hollowed out by water, but were evidently dents made by stranding ice or by erratics, for the clay forming the margins of the pits was generally much disturbed and contorted. Some of these pits were filled with finer materials and 'probably mark the spots where large erratics were formerly deposited, though becoming again frozen into the ice-foot, they were lifted out and transported to fresh sites.' Mr. Reid examined about a hundred of such pits, and came to the conclusion that all the evidence pointed to the action

[1] Pengelly and Heer, *Philosophical Trans.* 1862, pp. 1019, 1039.
[2] *Quart. Journ. Geol. Soc.* vol. xlviii. p. 344.

of drift-ice grounding on a fore-shore, dropping its erratics between tide-marks, where they were pressed deeper and deeper into the clay by the weight of the ice-pack. Such boulders as still projected above the surface of the clay would be liable to become frozen into a new ice-foot or mass of pack-ice, and might thus be lifted out of their pits and carried away again at the rise of spring tides. Perhaps some of the depressions in the surface of the clay may have been caused by the stranding and revolving of ice-masses, but Mr. Reid thinks that the evidence is suggestive rather of quiet water in a sheltered bay. Most of the erratics consist of Tertiary and Cretaceous rocks, and probably came from the Isle of Wight, while the hard crystalline and Palæozoic rocks may have travelled from the coasts of Cornwall or Brittany.

Mr. Reid shows that this old beach with its ice-floated erratics is older than certain marine, estuarine, and fresh-water deposits which occur in the same neighbourhood. At Selsey Bill the marine beds have yielded a molluscan fauna of southern type, and were probably deposited at depths of 10 to 25 fathoms. They are overlaid by estuarine mud, containing shells and land-plants, and obviously accumulated between tide-marks, while this mud in turn is capped by littoral sand and shingle. All these deposits, according to Mr. Reid, belong 'to one series, and point to a gradual shoaling of the water and change from an open sea to a sheltered estuary.' Above these comes a sheet of 'coombe-rock' (rubble-drift), the origin of which has already been discussed. At other places on the same coast estuarine and fresh-water beds are met with occupying a similar strati-graphical position. There can be no doubt, therefore, that in Sussex we have clear evidence of two cold epochs separated by one of genial conditions. The interglacial beds are fortunately highly fossiliferous, and have yielded many molluscs, beetles, and plants, with some mammalian remains. The molluscs include *Corbicula fluminalis* and *Hydrobia marginata*, and form an assemblage which 'is certainly not boreal.' The plants, Mr. Reid tells us, denote 'climatic conditions similar to those of England at the present day. The oak, wild-cherry, cornel, elder, guelder-rose, and hazel are the only trees yet met with, but of these the cornel does not extend into

the north of England. All except one of the plants still live in England.' The only mammalian remains hitherto found belong to rhinoceros and elephant, but the squirrel is suggested by the occurrence of gnawed hazel-nuts.[1]

Mr. Reid correlates these Sussex interglacial beds with those which underlie the upper boulder-clay of the Humber. In this view the erratics of Pagham, &c., represent the lower boulder-clay of the North, while the 'rubble-drifts' (coombe-rock) are the equivalents of the upper boulder-clay. At present it is impossible to point to any deposits in Southern England that we can take to be the representatives of the great moraines of our mountain-regions. Possibly the arctic-alpine flora of Bovey Tracey may be on this horizon, and some of the superficial drifts doubtless belong to the same stage, but it will be difficult to distinguish these from similar accumulations of earlier times.

It will be noted that during the dispersal of the Pagham erratics the sea-level in Southern England was much the same as it is now. The sections on the Sussex coast do not tell us what happened after the disappearance of glacial conditions. There is a decided break in the succession between the erratic deposit and the overlying marine interglacial beds. We may infer, however, that during the unrepresented interval England may have become joined to the Continent, so as to allow of the immigration of the

[1] See further an interesting paper by Mr. A. Bell, 'Notes on a Post-tertiary Deposit in Sussex' (*Annual Report of Yorkshire Philosophical Society for* 1892, p. 58). Mr. Bell gives a long list of the marine, fresh-water, and terrestrial remains. The fauna, he remarks, has no equivalent in the British post-tertiaries, not only because of its purely southern aspect, but for the number of species in common with those of the older and undisturbed Pliocene deposits of the east coast, including some of which the present habitat is unknown. The mammals include *Capra hircus*, *Cervus elephus*, *Bos primigenius*, *Rhinoceros leptorhinus*, Owen, *Elephas antiquus*, *E. meridionalis*?, *E. primigenius*, *Equus caballus*. Mr. Bell is of opinion that the large erratics in the Sussex shore-deposits were transported at a period subsequent to the formation of the fossiliferous beds described above. But Mr. Reid's observations seem to be conclusively against this view. The last-named geologist has since discovered another deposit similar to that of Selsey. This bed occurs on the Hampshire coast, near Stone, and has yielded a fauna and flora identical, so far as it goes, with the interglacial beds described above. One of the plants represented is the South European maple (*Acer monspessulanum*), which occurs also in the bed at Selsey, although Mr. Reid had not recognised it as such when his paper describing that deposit was written. This tree does not at present range nearer to Britain than Western Germany and Southern France. (*Quart. Journ. Geol. Soc.* vol. xlix. p. 325.)

interglacial fauna and flora. Thereafter submergence ensued until the land became drowned to a depth of not less than 125 ft., as shown by the raised beach discovered by Mr. Prestwich at Portsdown Hill.[1] The absence of any evidence of greater submergence than this having taken place either in Southern or Eastern England increases the suspicion that the contemporaneous depression of Lancashire and Cheshire has been exaggerated, and that the supposed proofs of great submergence have probably been misinterpreted. Here we may note that in Southern England there is an absence of those extensive sheets and mounds of well-washed sand and well-rounded gravel which form the bulk of the 'Middle Sands' of Lancashire, &c. Such deposits are, in these islands, confined to regions which on other and independent evidence can be proved to have been thickly mantled with ice, and their absence from the south of England, therefore, is only what might have been expected.

Having sketched the history of the accumulations which by common consent are included in the glacial series, we may now take a brief glance at those deposits which in the low grounds of England overlie the upper boulder-clay and are generally spoken of as *postglacial*. The term is a convenient one, but it is not without disadvantages, because it can be, and indeed has been, used with widely different significations. Thus deposits overlying the lower boulder-clay in the southern part of England are often described as *postglacial*, in the sense that they are of later date than the *mer de glace* that overflowed that region. But some of these deposits, as we know, are older than the upper boulder-clay, and cannot therefore be postglacial with reference to the general geological history of the country. So, in like manner, many of the accumulations that rest upon the upper boulder-clay are postglacial in relation to that deposit, but are certainly older than the later developments of glacier-ice in our mountain regions. Others, again, are no doubt of more recent origin than all the valley-moraines of Wales and the Lake District of Cumberland, and are therefore truly postglacial in the larger meaning of the word. A term susceptible of such different meanings is unsatisfactory, unless we define

[1] *Quart. Journ. Geol. Soc.* vol. xxviii. p. 38.

beforehand in what particular sense we intend to use it. I may premise, therefore, that in the succeeding short account of the 'postglacial' deposits of England, I refer to accumulations which are younger than the upper boulder-clay. When these deposits come to be better known than they are at present, it will probably be found that they are not all truly postglacial—but that while some are older, others are younger than the latest recrudescence of glaciation in Britain.

It has long been a familiar fact that 'peat with trees' frequently appears at and below the present sea-level. The so-called 'submerged forests' of England furnish us with precisely the same kind of evidence as those of Scotland, and it is unnecessary, therefore, to treat of them in detail.[1] Attention will be confined to what seems to me to be the general gist of the story they have to tell us.

The broad facts, then, are these:—At a depth from the surface, varying from 20 to 60 or 70 ft., occurs a layer of peaty matter enclosing and covering forest-trees, the stools of which are often rooted in an ancient soil. Above this buried land-surface appear lacustrine, or estuarine, or, as the case may be, marine deposits. Next comes a second forest-layer, overlaid by similar accumulations. It is this second forest-bed which is so frequently exposed upon the present foreshores. As regards their stratigraphical position there can be no doubt that these buried forests are all younger than the upper boulder-clay.[2] In the north-east of England this is most clearly seen. In that region the lower forest-layer rests often directly on the surface of the Hessle boulder-clay, which is penetrated by the roots of the old trees. It is obvious, of course, that there must be a very considerable break in the succession between the epoch of the upper boulder-clay and that of the buried forests. The forests undoubtedly indicate genial climatic conditions, and from the character of the trees and the position of the deposits we can have no hesitation in correlating the English buried forests with those that occur in the maritime districts of Scotland.

[1] For a particular account of the 'submerged forests' see *Prehistoric Europe*, chaps. xviii., xix.

[2] According to Mr. Kendall, the peat, &c., exposed upon the sea-coast of North Lancashire is overlaid inland by upper boulder-clay (see *ante*, p. 369).

It will be remembered that these last rest upon the accumulations of the 100-ft. beach with its arctic shells. Of this old beach, however, we seem to have no trace in England. Nevertheless there is certain evidence, which, in the knowledge we have of the clearly exposed succession in Scotland, appears to be highly suggestive of similar climatic changes having supervened in England. Mr. Reid[1] has shown that in Holderness the postglacial deposits rest upon a highly eroded surface of the Hessle boulder-clay and the fluvio-glacial gravels associated with that clay. According to Mr. Lamplugh, these gravels were laid down during the retreat of the last great *mer de glace* that invaded the low grounds of Holderness from the North Sea. The general character of the gravels in question and the mode of their distribution suggest, he says, 'a picture of bleak frozen chalk wolds, silent and deserted, and deeply covered by snow in winter, and in summer streaked and drenched with melting snow and muddy chalk detritus, and of dells sometimes ice-bound, sometimes held by rills and streams and floods of icy water sweeping out into the low ground with swift floe-laden currents, submerging much of the wide uneven plains which then stretched far away into the present bed of the North Sea, and reducing it to a state resembling the descriptions we have of the Siberian tundras in flood tide.'[2]

After the disappearance of glacial conditions the land must have been subjected to a long period of moderate denudation—probably not unlike that which is now going on—during which the old glacial covering of the country was deeply incised and worn into troughs and hollows by rills and streams. And this must have taken place at a time when the land stood relatively higher, and extended far into what is now the bed of the North Sea. What the character of the climate may have been under these conditions we can only conjecture. All we can be sure of is that it was not extreme. Unfortunately no deposits belonging to this period of erosion have yet been recognised.[3]

[1] 'The Geology of Holderness,' *Mem. Geol. Survey*, 1885.

[2] *Proc. Yorks. Geol. and Polytech. Soc.* vol. viii. p. 252.

[3] Yet surely these must occur, and should yet be met with in some one of the numerous silted-up lakelets and meres of Holderness. I would venture to suggest that the fresh-water bed described by Mr. Reid as overlying the inter-

Filling up the hollows of the eroded surface of glacial clays and gravels come the 'postglacial' deposits with their abundant vegetable remains. Now at the base of these accumulations occurs a bed of peaty matter containing leaves of the Arctic birch (*Betula nana*), which, as Mr. Reid remarks, 'is so characteristic a northern form that it seems sufficient evidence of a colder climate.' It is clear, then, that long after the disappearance of glacial conditions in Holderness, after the upper boulder-clay and its overlying gravels had been much denuded—an arctic-alpine flora appeared. This, one can hardly help suggesting, represents in all likelihood the cold stage which is evidenced by the 100-ft. beach of Scotland, and by the large valley-moraines and ground-moraines of the Highlands and other mountain-tracts.

After the Arctic birch had vanished from Holderness under the influence of changing climatic conditions, a temperate flora and fauna eventually occupied the ground. Among the trees of the lower buried forest the most abundant was the oak, which attained large dimensions, besides alder, hazel, willow, &c. Man's presence is suggested by traces of fire, which were discovered in the old forest at Hull Docks. From alluvial deposits in the same neighbourhood have come remains of stag, great Irish deer, horse, cave-lion, and perhaps mammoth, for there is some doubt as to whether the last-named really belongs to this horizon. The evidence of trees and animals alike points to genial climatic conditions.[1]

After these genial conditions had obtained for some time the sea advanced upon the land, just, as we have seen, was

glacial gravels at Kelsea Hill may belong to the stage in question. It seems also not at all unlikely that the bottom-beds of the Hornsea-Mere alluvia may date back to the same epoch, and that the bed, with Arctic birch referred to in the following paragraph above, may not everywhere form the base of the so-called postglacial deposits of Holderness.

[1] The animal remains referred to have come chiefly from the old alluvia of Hornsea Mere, and are assigned unhesitatingly by Mr. Reid to the horizon of the buried forests. There is no evidence to invalidate this conclusion; on the other hand, there is nothing to show that the beds, from which some of the animal remains have come, may not belong to a lower horizon than the *Betula-nana* bed. I suspect that the Irish deer, the lion, and the mammoth do not belong to the epoch of the buried forest, but to an earlier stage—later than the upper boulder-clay, but earlier than the *Betula-nana* bed. For further remarks on this subject see Chapter XXVIII., where the glacial and postglacial deposits of Ireland are described.

the case in Scotland. The beds of warp or estuarine silt which overlie the lower buried forest of the Humber are exactly equivalent to the Carse-deposits of the Scottish estuaries. We know that in the North-west Highlands small glaciers at this stage descended to the sea, but the warp of the Humber yields no evidence of colder conditions than the present. What the amount of depression in Eastern England may have been at this time it is hard to say. The erosion of the coast-line is so rapid that any raised beaches that may formerly have existed there must have been long ago destroyed.[1]

The second forest-bed overlies the warp-beds, and is seen exposed here and there on the foreshore at or about low-water mark. It indicates a former greater extension of the land seawards, or a lower sea-level, but the difference between that level and the present need not have been more than a few feet.

The general succession thus indicated is repeated more or less clearly in the Fenland, and on the coasts of other parts of England.[2] In the Fenland, as we might have expected, the order in which the deposits occur is practically the same as in Holderness—with this difference, that in the former district the upper boulder-clay is wanting. Hence in the Fenlands the postglacial and recent accumulations rest upon a highly denuded surface of lower boulder-clay and interglacial beds (March gravels). There is thus a greater break in the succession here than farther north. The basin in which the true Fen-beds lie has been excavated partly in Jurassic strata and partly in glacial deposits. Here and there the level surface of the Fenland is interrupted by slight hills and rising grounds, which form islands, as it were, in the wide expanse. These islands are composed of lower boulder-clay, capped with interglacial fluviatile and marine deposits (March gravels, &c.), which, according to Mr. Skertchly, indicate the former existence of a land higher than the

[1] At Saltburn a raised beach occurs at a height of 40 ft. above high-water.

[2] See *Prehistoric Europe*, chaps. xviii. and xix., and the authorities therein cited. An interesting account of the buried trees and peat of the Thames Valley, with copious references to original sources of information, is given by Mr. Whitaker, 'Geology of London,' vol. i. (*Mem. of Geol. Survey*).

present, when the coast-line was not so far east. It is obvious, therefore, that a wide interval separates the formation of the Fen-beds from the interglacial gravels.

The lowest of the Fen-beds consist of gravels which seem to form the basement accumulations everywhere throughout the district. They are unfossiliferous, but are believed by Mr. Skertchly to be in all probability of marine origin. Overlying these gravels occurs a buried forest, which seems to be almost invariably present throughout the Fenland. The trees include oak, elm, yew, birch, hazel, alder, willow, and pine (*Pinus sylvestris?*)—all, except pine, still natives of the district. The presence of this old forest, thirty feet below the present sea-level, speaks of course to a former wider extent of land. The forest is covered with peat, composed chiefly of *Hypnum fluitans*. The succeeding deposits consist of marine silt, overlying which we encounter a second buried forest. To this stage probably belong the submerged forests which occur upon the sea-coast at Holme and Hunstanton in Brancaster Bay and at Skegness, and northward on the Lincolnshire coast. The second forest-bed of the Fenland is overlaid by marine silt, with peat and sporadic layers of trees, which point to the gradual silting up of the Wash, and the alternate prevalence of humid and dry conditions on the reclaimed areas. It may be added that, according to Mr. Clement Reid, the Arctic birch has been met with underneath the oldest of the Fenland peat-beds.

Space will not allow of any particular description of the similar successions met with in other parts of England;[1] but I may here tabulate the general results obtained from a few well-known localities, beginning with Holderness and the Fenland:—[2]

Holderness.

1. Layer with Arctic birch.
2. Lower buried forest and peat.
3. Marine accumulations.
4. Upper buried forest and peat.
5. Marine and fresh-water deposits.

[1] For a general account of the Peat and Submerged Forests of England see Woodward's *Geology of England and Wales*, 2nd ed. p. 522, where copious references to the literature of the subject will be found.

[2] Attempts have sometimes been made to explain away the evidence of submergence afforded by the peat and forest-beds which occur below sea-level.

Fenland.

1. Layer with Arctic birch.
2. Lower buried forest and peat.
3. Marine accumulations.
4. Upper buried forest and peat.
5. Marine deposits, peat, shell marl, and sporadic forest-layers.

Cornwall.

1. Layer with Arctic birch, not known.
2. Lower buried forest and peat.
3. Marine and estuarine deposits.
4. Upper buried forest and peat in stream-tin sections, and submerged forests and peat on foreshore.
5. Marine deposits.

Cheshire, &c.

1. Layer with Arctic birch, not known.
2. Lower buried forest and peat.
3. Marine deposits.
4. Upper buried forest, peat, and lacustrine deposits.
5. Marine deposits.

Seeing that the 'postglacial' and recent accumulations of these separate districts agree so closely, the conviction is

It has been suggested, for example, that the trees might have grown at the level at which they are now found, behind some bank or bar, until the latter gave way and allowed the sea to overwhelm the forest-land. When we remember that some of the buried forests occur at depths of 50 and 60 ft. below the sea, and that the phenomena of submerged land-surfaces are common all round our coasts, we may well ask what kind of banks or bars would be required to protect forests growing under the conditions supposed. What were our rivers doing when such impervious breakwaters were allowed to keep out the sea from what are now estuaries and bays? (See some pertinent remarks on this subject by Mr. J. Starkie Gardiner, *Geol. Mag.*, Dec. III. vol. ii. p. 145.) Mr. Shone has recently tried to show that the submerged peat- and forest-beds of the Mersey, and by implication those of other districts, have been lowered to their present position by subterranean erosion (*Quart. Journ. Geol. Soc.* vol. xlviii. p. 96). There are two well-marked forest-beds in the maritime tracts of Cheshire and Lancashire; the lower of these Mr. Shone supposes flourished very little above the water-level. Owing to the erosive action of underground water, the surface of the ground, he thinks, was gradually lowered until the site of the forest became a morass, and this, owing to continued subterranean erosion, was eventually submerged, and became covered with tidal silt. Then, for some unexplained reason, subterranean erosion was interrupted, and the upper forest-bed gradually overspread the tidal silt or clay. After forests had flourished for some time, the cause of the interrupted drainage was removed, subterranean erosion and consequent lowering of the surface was resumed, and the forest was by-and-by converted into a morass, which, as before, was invaded by the sea and buried under tidal silt. Now, although I believe in subterranean erosion, I cannot suppose that beds of sand and gravel are swept out in the wholesale manner described by Mr. Shone. He speaks of 'the sudden rush of subterranean water' through such beds much in the way that we should describe the course of an underground stream in limestone. But no such violent flow can take place in beds of sand and gravel. When a series of porous and impervious beds of sand and clay are truncated by a valley, underground water issues from the porous beds, carrying with it some of the sand lying at or near the outcrops. The outcrops thus gradually retreat, and collapse of the superjacent beds eventually results. Lowering of the sur-

:ed upon us that such close parallelism cannot be the ılt of mere local circumstances, but must be due to the valence of similar conditions over a wide region. In only of the districts has the layer with Arctic birch been ected, but we may well believe that the occurrence of t plant is sufficient evidence of a generally cold climate. ıen Arctic birch was growing in the east of England, and en the seas round Scotland were charged with Arctic luscs, we cannot suppose that other parts of these islands e in the enjoyment of genial conditions. The general ence of the lower buried forest, at depths of 20 to 60 ft. w the existing sea-level, points not only to a considerable nge of climate, but to a former higher level of the land. decay of this ancient forest, its entombment in peat, and sequent submergence, are indicative of changed climatic geographical conditions. It is true that the marine osits themselves yield no direct evidence of colder conons than the present, but we must read this evidence in nection with that supplied by the peat-bogs of inland ricts and by the Carse-deposits, raised beaches, and 'postial' moraines of Scotland. The decay of the old forests, the growth of the overlying peat, seem to me to indicate nged climatic conditions which were accompanied by a ted submergence of the land. During this period of subgence immense quantities of vegetable débris were floated n by the rivers. The subsequent retreat of the sea to a

therefore, can take place only at or near the point of outlet of the springs. according to Mr. Shone's hypothesis, the underground water which is sed to have caused the subsidence of the upper peat and forest-bed must issued at a depth of some 20 ft. below the sea-level—that being the of the lower buried forest from the surface. To have enabled it to do e inland stores of subterranean water must have been large, and the line turation must have risen to a height sufficient to enable the hydrostatic are to overcome the weight of sea-water. But no one can suppose that conditions obtain in the lowlying drifts of Cheshire. To consider Mr. 's hypothesis in detail would unduly extend this note. I would only point ıat even if we admitted that subterranean erosion could lower a surface way he supposes, it is hard to see how the action could be equally spread ın area of many square miles, as in the case of the buried forests of the ish estuaries and the Fenland. In many places, indeed, action of the is impossible, since the old forests are rooted in impervious clay that rests diately upon solid rock. The very fact that buried forests occur at so different and widely-separated points and under all conditions of underıd structure is sufficient to prove that our submerged forests belong to the category as our raised beaches—they are evidence of an oscillating sea-

somewhat lower level than the present seems to have been followed or accompanied by a return of genial conditions when forests again overspread what are now our maritime regions. Eventually the sea again advanced upon the land, and the forests decayed and became enveloped in peat as before.

When I come to sum up the evidence bearing on the climatic and geographical changes of glacial and post-glacial times, we shall find that genial climatic conditions are almost invariably associated with a wide land-surface, while cold conditions are just as constantly accompanied by evidence of submergence.

In concluding this rapid review of the English 'post-glacial' accumulations—those, namely, which are of later date than the upper boulder-clay—I may add that they have never yielded any trace of Palæolithic man. The relics of man met with in the oldest 'postglacial' deposits are of Neolithic age. We may note also that none of the great pachyderms of southern habitats (such as *Hippopotamus*, *Elephas antiquus*, *Rhinoceros leptorhinus*, &c.), that were contemporary with Palæolithic man, has ever been recorded from a 'postglacial' horizon.

CHAPTER XXVIII.

GLACIAL PHENOMENA OF IRELAND.

nfossiliferous till—Lower boulder-clay—Middle shelly sands, &c.—Upper boulder-clay—Moraines of mountain-districts—Eskers—Fresh-water beds underlying peat-bogs—Corrie glaciers—Submerged peat, &c.—Raised beaches—The glacial succession in the British Islands.

NO part of the British Islands exhibits better than the wilder districts of Ireland the effects of severe glaciation. In he rugged western areas of Galway and Mayo especially, ounded and well-rubbed rocks and heaps of glacial deposits ccur everywhere. The striæ upon the rocks, and the direc- ion in which the till has travelled, mark out clearly the path aken by the great sheet of ice which wrapped up Ireland even s it enveloped Scotland.

The oldest glacial deposit recognised by Irish geologists a tough stony clay similar in all respects to the Scottish ll. This is the chief drift of the central plain of Ireland. t usually lies upon a smoothed and striated surface of rock, nd its stones and boulders are more or less blunted and ell glaciated. Occasionally it contains nests or lenticular eds of sand and gravel, and sometimes of fine laminated clay. ot infrequently the deposit is arranged in a series of broad arallel ridges and banks ('drumlins'), the trend of which as been ascertained to coincide precisely with the direction aken by the old ice-flows.[1]

In the northern and eastern districts of Ireland it is

[1] See this beautifully shown upon the map accompanying a paper 'On the eneral Glaciation of Iar-Connaught and its Neighbourhood,' &c., by Messrs. inahan and M. H. Close. For detailed information on the Irish glacial depo- ts the reader must consult the publications of the Geological Survey, and apers by Messrs. Kinahan and Close in the *Dublin Quarterly Journal of cience*, in which he will find references to other authorities on the subject. ee also *The Glacial Geology of Great Britain and Ireland*, by C. Lewis. For he general direction of glaciation in Ireland during the climax of the Glacial eriod see Plate I.

interesting to find a series of gravel and sand beds resting upon and covered by stony clay.[1] These intercalated beds contain a number of sea-shells belonging, for the most part, to species now living, but indicating somewhat colder conditions than obtain at present in the neighbouring seas. The beds are believed to be the equivalents of the middle sand and gravel series of the north-west of England. In County Antrim, near Ballycastle, they form, according to Professor Hull,[2] conspicuous terraces rising on the flanks of the hills to a height of 600 ft. With regard to the drifts of the northern and central districts, there can be no doubt that we have the Lancashire type very well displayed. Mr. E. T. Hardman has described[3] a number of sections where the triple series is admirably shown. This arrangement holds good all through the counties of Tyrone, Armagh, and in such parts of Derry as Mr. Hardman was acquainted with, and he thought that 'the drift of the more central parts of Ireland, especially that of the Queen's County, Carlow, and Kilkenny, is equally susceptible of a tripartite arrangement.' The section of the drift deposits in Dublin county, cited by Professor Hull, also affords clear proof that two boulder-clays separated by intervening gravels are characteristic of the drift in that neighbourhood. The annexed section (Fig. 71) has been kindly sent to me by Professor Hull. It shows how the three members of the drift have been deposited on an inclined bank of limestone and subsequently denuded.

The fossiliferous gravel-beds in question have been traced by Mr. J. Kelly[4] and the Rev. Maxwell Close[5] up to a height of 1,300 ft. on the flanks of the Dublin and Wicklow Mountains; and they are recorded by the Geological Survey as occurring at an elevation of 1,235 ft. on Montpelier Hill.[6] In County Wexford certain highly fossiliferous gravels ('manure gravels') cover a wide area, and attain in places a thickness of more than 150 ft. They extend from the coast up to heights of 200 and 300 ft., and on the flanks of the

[1] Professor Harkness, *Geological Magazine*, vol. vi. p. 542; Professor Hull, *op. cit.* vol. viii. p. 294.

[2] *Physical Geology and Geography of Ireland*, p. 11.

[3] *Journ. Roy. Geol. Soc. Ireland*, vol. iv. (new series) p. 73.

[4] *Journ. Geol. Soc. Dublin*, vol. vi. p. 133.

[5] *Journ. Roy. Geol. Soc. Ireland*, vol. vi. p. 36.

[6] *Explanations of Sheets* 102 and 112 (Geol. Survey Maps), p. 67.

Firth Mountain they even reach 400 ft. above the sea. Professor Harkness showed that these gravels were overlaid in places by boulder-clay. Unfortunately it is not known whether or not they rest upon boulder-clay. Harkness, however, had no doubt that they were of the same age as the shelly gravels which farther north are included between an upper and a lower boulder-clay.

The upper boulder-clay has thus been identified over considerable areas in the central and eastern portions of the island. In the western parts it has not been recognised. It is probable, however, that much of the boulder-clay met with in those regions really pertains to the upper rather than the lower series. The two deposits, as Professor Hull remarks, may readily be confounded, they are generally so much alike, and when only one is present the tendency is to assign it to the lower horizon.

In the mountainous districts of Ireland, as in those of England and Scotland, terminal and

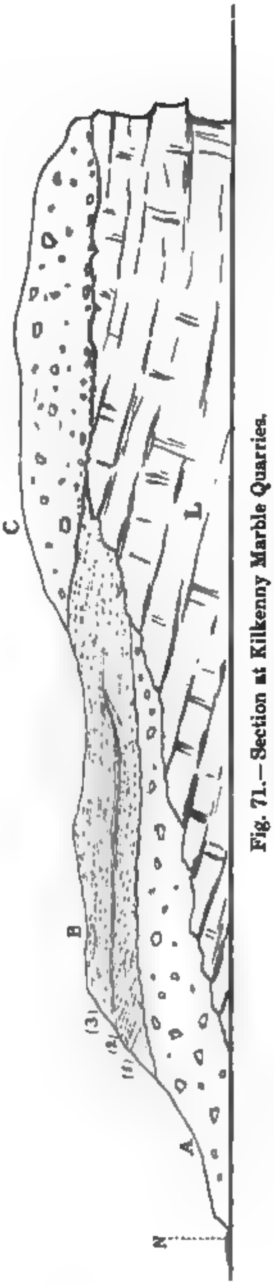

Fig. 71.—Section at Kilkenny Marble Quarries.

A, Lower boulder-clay, with large blocks of limestone and grit; 25 to 35 ft. thick.

B, Middle (interglacial) gravels { 3, Limestone-gravel and sand, stratified . . . ; 2, Bed of loamy sand . . . ; 1. Earthy gravel, current-bedded, pebbles water-worn } 10 to 25 ft. thick

C, Upper boulder-clay; brown clay with subangular and rounded boulders; 20 to 25 ft. thick.

L, Limestone. N, Valley of the River Nore.

lateral moraines, perched blocks, and other evidence of local or valley-glaciers are conspicuous enough. They are well seen, for example, amongst the mountains of Wicklow, Waterford, Kerry, Clare, Galway, Mayo, &c. These moraines indicate the presence of very considerable glaciers, which in some cases have flowed in a different direction from that followed by the *mers de glace* underneath which the boulder-clays were accumulated. A good example of this is seen along the southern margin of the Connemara Mountains, where, according to Hull, the earlier general glaciation has been obliterated by the action of the later local glaciers.

The great elongated ridges of gravel called eskers, and the widespread deposits of similar materials which are met with so abundantly, especially in the central parts of Ireland, have long been famous. They are remarkable for being frequently dotted over with large erratic blocks. The origin of the eskers has been a much-debated question. There can be little doubt, however, that they have been formed in the same way as the gravel ridges of the Scottish Lowlands and the åsar of Sweden. Like these the eskers are also unfossiliferous. Mr. Kinahan has strongly upheld their marine origin. I was formerly of the same opinion, but having long since seen reason for believing that the sea had no share in the formation of the Scottish gravel ridges, which are of precisely the same character as the Irish eskers, I now look upon the latter as having been heaped up principally by the action of subglacial and supraglacial waters during the final melting of the confluent glaciers.

On the sea-coast and in the interior of the country, sandhills are very frequently found amassed at or near the mouths of valleys. In the neighbourhood of the sea they form undulating dunes, which are continually being influenced by the winds. Mr. Kinahan was, I believe, the first to point out their connection with the valleys. He tells us that they not only occur at or near the mouths of the valleys, but the greater and more extensive the valley, the greater, he says, is the accumulation of sand. He considers that the sand of which these hummocks consist was originally brought down by rivers at a time when glaciers occupied the

s[1]—an inference which is strongly supported by the rance of similar phenomena in Scotland. The same r has described the occurrence under the till in Ire- of what he calls 'preglacial drift,' which occasionally ns the remains of trees.[2]

ie general succession of events during the glacial period land would seem therefore to be closely analogous to experienced in Western England. The lower boulder- ndicates the epoch of maximum glaciation when all d was smothered in ice—only the tops of the higher tains appearing above the surface of the *mer de glace natakkr*. The movement of the ice in the north-east island was obviously influenced by the presence of the ent Scottish *mer de glace*. This is shown by the er in which the striations in the maritime districts of n and Down are deflected to north-west and south-east. ier interesting point connected with the primary glacia- f the country is the fact that the ice-shed or main axis cial movement did not coincide with any mountain- On the contrary, as the Rev. Maxwell Close has i, the ice-parting extended along the northern portion low-lying Central Plain, from Lough Corrib and Lough in the west to Lough Neagh in the east. From this ine the ice flowed away in opposite directions towards a, suffering endless modification and deflection from esence of the various mountain-masses it encountered path. The fact that the axis of glacial movement was he Central Plain does not indicate that there has been ange since glacial times in the relative elevations of rface. Neither mountain-masses nor ranges are neces- o the production of an ice-sheet: all that is required a low temperature with sufficient precipitation. Were imatic conditions of the Ice Age to return, the axis of l movement in Ireland would doubtless extend across me tract of low-lying land. It is beyond my purpose tch, however briefly, the track followed by the great eet all over the country; but the reader will gather

[1] *Geological Magazine*, vol. viii. p. 155.
[2] *Dublin Quarterly Journal of Science*, vol. vi. p. 249.

some general notion of the direction of flow from the sketch-map[1] (Plate I.).

The shelly gravels overlying the lower boulder-clay have invariably been considered as of purely marine origin. That some are truly marine, in the sense of being undisturbed marine deposits, is highly probable. But the same doubt attaches to those accumulations as to the equivalent deposits in the north-west of England. It would seem certain that they really denote some degree of submergence, but whether those at the higher elevations are proofs of depression to that extent is very doubtful. Mr. Close has pointed out that flints occur in the high-level shelly gravels, as indeed they do very commonly in the beds at lower levels. The presence of these erratics he attributes to floating ice, but it seems much more likely that they have been derived from the morainic materials of the old ice-sheet, and are therefore no proof of submergence. Much careful re-examination will be required to discriminate between truly undisturbed marine deposits and shelly deposits of fluvio-glacial origin. For the present all we can say is that the interglacial gravels indicate a submergence of probably several hundred feet—perhaps as much as 400 or 500 feet. I may add that the fauna of the gravels denotes for the sea a temperature not unlike that of the present Irish Sea, but somewhat colder.

So far as I am aware, no fresh-water or terrestrial accumulations have been met with occupying an interglacial position. We cannot, therefore, affirm that the ice-sheet of the lower till melted away and left a wide land-surface exposed. But if in England and Scotland no submergence followed immediately upon the disappearance of that ice-sheet, but on the contrary the land extended seawards farther than it does to-day, it is hardly likely to have been otherwise with Ireland. However that may have been, submergence did at last ensue—a submergence which was doubtless contemporaneous with that experienced in England and Scotland.

[1] For fuller details, see Maxwell Close 'On the General Glaciation of Ireland,' *Journ. Roy. Geol. Soc. Ireland* (1886), vol. i.; *Geol. Mag.* vol. iv. p. 234. Hull's *Physical Geology and Geography of Ireland* and Kinahan's *Geology of Ireland* give excellent descriptions of the glacial phenomena, and furnish their readers with many references to original sources of information, chief among which are the maps and memoirs of the Geological Survey. See also Lewis's *Glacial Geology of Great Britain and Ireland.*

The upper boulder-clay is the product of a second ice-sheet which, like the corresponding ice-sheet of the sister land, did not attain the dimensions of the earlier *mer de glace.* During the formation of this upper till the Irish Sea was occupied by a great glacier to which the ice-flow coming from Eastern and Central Ireland was contributory. To what extent the western portion of Ireland was occupied by ice at the same time we cannot be certain. Perhaps the ice-sheet of those regions was not much inferior in thickness or extent to that of the preceding glacial epoch; but until the deposits have been more critically examined this point must remain undecided.

There is evidence, as we have seen, in Ireland, just as in the sister island, to show that subsequent to the disappearance of the general *mer de glace*, great glaciers ('district glaciers') existed in the mountainous parts of the country. These are generally believed to have been the impoverished successors of the preceding *mer de glace*; but they come under the same category as the similar glaciers of Scotland and England, and belong to a separate and distinct stage of the Glacial Period. I am well aware that no interglacial beds have been detected underlying the moraines of the large 'district glaciers.' But I suspect that we shall be eventually led to assign to this horizon certain deposits which have hitherto been considered as of 'postglacial' age, merely from the fact that they are found resting upon the surface of boulder-clay. The deposits to which I refer are the freshwater clays that so frequently underlie the peat-bogs of Ireland. These clays are famous on account of the numerous remains of the great deer (*Cervus megaceros*) which they have yielded. An interesting account of the beds in question was given some years ago by Mr. Williams,[1] who, as a collector of Megaceros remains, had the best opportunity of ascertaining the nature of the deposits in which these fossils occur. He gives a section of Ballybetagh Bog, nine miles south-east of Dublin, which is as follows:—

6. Peat.
5. Greyish clay.
4. Brownish clay, with remains of Irish deer.
3. Yellowish clay, largely composed of vegetable matter.
2. Fine tenacious clay, without stones.
1. Boulder-clay.

[1] *Geol. Mag.* 1881, p. 354.

The beds overlying the boulder-clay are evidently of lacustrine origin. The fine clay (No. 2), according to Mr. Williams, is simply reconstructed boulder-clay. After the disappearance of the *mer de glace* the land would for some time be practically destitute of any vegetable covering, and rain would thus be enabled to wash down the finer ingredients of the boulder-clay that covered the adjacent slopes, and sweep them into the lake. The clay formed in this way is described as attaining a considerable thickness near the centre of the old lake, but thins off towards the sides. The succeeding bed (No. 3) consists so largely of vegetable débris that it can hardly be called a clay. Mr. Williams describes it as a 'bed of pure vegetable remains that has been ages under pressure.' He notes that there is a total absence in this bed of any tenacious clay like that of the underlying stratum, and infers, therefore, that the rainfall during the growth of the lacustrine vegetation was not so great as when the subjacent clay was being accumulated. Remains of Irish deer occur resting on the surface of the plant-bed and at various levels in the overlying brownish clay, which attains a thickness of three to four feet. The latter is a lake-sediment, containing a considerable proportion of vegetable matter, interstratified with seams of clay and fine quartz-sand. According to Mr. Williams, it was accumulated under genial or temperate climatic conditions like the present. Between this bed and the overlying greyish clay (thirty inches to three feet thick) there is always in all the bog-deposits examined by Mr. Williams a marked line of separation. The greyish clay consists exclusively of mineral matter, and has evidently been derived from the disintegration of the adjacent granitic hills. Mr. Williams is of opinion that this clay is of aqueo-glacial formation. This he infers from its nature and texture, and from its abundance. 'Why,' he asks, 'did not this mineral matter come down in like quantity all the time of the deposit of the brown clay which underlies it? Simply because, during the genial conditions which then existed, the hills were everywhere covered with vegetation; when the rain fell it soaked into the soil, and the clay, being bound together by the roots of the grasses, was not washed down, just as at the present time, when there is

hardly any degradation of these hills taking place.' He mentions, further, that in the grey clay he obtained the antler of a reindeer, and that in one case the antlers of an Irish deer, found embedded in the upper surface of the brown clay, immediately under the grey clay, were scored like a striated boulder, while the under side showed no markings. Mr. Williams also emphasises the fact that the antlers of the Irish deer often occur in a broken state—those near the surface of the brown clay being most broken, while those at greater depths are much less so. He shows that this could not be the result of tumultuous river-action—the elevation of the valley precluding the possibility of its receiving a river capable of producing such effects. Moreover, the remains show no trace of having been water-worn, the edges of the teeth of the great deer being as sharp as if the animal had died but yesterday. Mr. Williams thinks that the broken state of the antlers is due to the 'pressure of great masses of ice on the surface of the clay in which they were embedded, the wide expanse of the palms of the antlers exposing them to pressure and liability to breakage.' In many cases the antlers thus snapped across were twelve or fourteen inches in circumference, and almost as hard and sound as ivory. It is remarkable that in this one small bog nearly one hundred heads of Megaceros have been dug up.

Mr. Williams' observations show us that the Megaceros-beds are certainly older than the peat-bogs with their buried timber. When he first informed me of the result of his researches (1880), I did not believe the Megaceros-beds could be older than the latest cold phase of the Ice Age. I thought that they were later in date than the last general *mer de glace*, and I think so still, for they obviously rest upon its ground-moraine. But since I now recognise that the upper boulder-clay is not the product of the last glacial epoch, it seems to me probable that the Megaceros-beds may be of interglacial age—that, in short, they may occupy the horizon of the interglacial deposits of the Baltic coast-lands The appearances described by Mr. Williams in connection with the 'grey clay' seem strongly suggestive of ice-action. Ballybetagh Bog occurs at an elevation of 800 ft. above the sea, in the neighbourhood of the Three Rock Mountain (1,479 ft.),

and during the epoch of great valley-glaciers the climatic conditions of that region must have been severe.[1] But, without having visited the locality in question, I should hesitate to say that the phenomena necessarily point to local glaciation. Probably frost, lake-ice, and thick accumulations of snow and *névé* might suffice to account for the various facts cited by Mr. Williams.[2]

Of later date than the moraines of the large 'district glaciers' are the smaller moraines which occur at the very heads of many of the mountain-valleys of Ireland. They betoken the former presence of local glaciers ('corrie glaciers') comparable to those occupying a similar position in Wales, England, and Scotland. So far as I know, there is no direct evidence to show that the epoch of these smaller ice-flows was separated by any mild interglacial epoch from the preceding stage of district glaciers. It has hitherto been taken for granted that the corrie-glaciers are simply the attenuated descendants of the earlier district glaciers. But, since we have clear evidence to show that the two series in Scotland were really separated by a wide interval of time, marked by the appearance of great forests and by oscillation of the sea-level, we can hardly doubt that in Ireland similar changes took place. As the Irish mountains do not attain an elevation of 3,500 ft., we meet with no representatives of the high-level corrie-lakes and moraines of Lochnagar, Cairngorm, and other mountain-regions in Scotland.

The submerged forests and peat, the inland bogs, and the raised beaches and recent alluvia of Ireland afford the same kind of evidence as the similar formations in England, and do not therefore call for special description. Mr. Kinahan has shown [3] that in the Irish bogs there are two well-marked

[1] I judge so from the fact that in South-western Scotland the snow-line during the epoch of large district glaciers stood at a height above the sea of only 1,600 ft. or thereabout. If such were the case in Scotland, the snow-line could not have been much higher in Northern Ireland.

[2] The description of the Cave of Ballynamintra by Dr. Leith Adams and Messrs. Kinahan and Ussher (*Trans. Roy. Soc. Dublin*, vol. i. (Ser. ii.) p. 177) suggests the probability that the remains of cave-bears, Irish deer, and man, occurring in the lower deposits of that cave, may belong to the same interglacial stage as that to which I would refer the Megaceros-beds underlying the peat-bogs.

[3] *Geology of Ireland*, p. 268. See also *Prehistoric Europe*, p. 458, where the reader will find a general description of the Irish 'postglacial and recent deposits,' and references to authorities who have dealt with the subject.

horizons of forest growth. The roots and trunks occurring under the peat consist principally of oak and yew, those in the upper forest layer (generally four to twelve feet above the oak-trees) being for the most part pine. In the lowland bogs of the west of Ireland both forest-layers occasionally consist of pines, and the same is the case in many of the bogs of the mountainous districts, as if in such places, Mr. Kinahan remarks, there had been two distinct ages of deal forests.

Submerged trees and peat occur at various places, particularly on the east and south coasts, along the shores of sandy bays, where they are exposed at low water. Raised beaches are also well developed—the lowest two (twenty feet and thirty-five feet above the sea respectively) corresponding apparently to the youngest raised beaches of the Scottish coasts. It is worthy of note that in both beaches relics of man, consisting of flint implements, kitchen-middens, &c., have been met with.

Before proceeding to our study of the superficial accumulations of the Continent it may be well to sum up in a few paragraphs the general results we have obtained from our review of the evidence furnished by the British deposits. In doing so I shall take account only of the principal changes —those, namely, which from their very nature could not have been mere local phenomena.

1. Weybourn Crag. The North Sea occupied by an Arctic fauna.

2. Forest-Bed of Cromer. Wider extent of land-surface, the southern portion of the North Sea a broad plain traversed by the Rhine. Climate temperate.

3. Leda-myalis Bed. Passage from temperate to boreal and arctic conditions. Submergence of the Rhenish alluvial plain.

4. Arctic Fresh-water Bed. Arctic flora in England.

5. Lower Boulder-clays. Maximum glaciation of the British Islands: *mer de glace* flows south to valley of the Thames; is confluent with the inland ice of Scandinavia.

6. Interglacial Beds—(Fresh-water alluvia, peat, &c., cave-deposits, marine beds). Britain probably continental; climate at first cold, then temperate. Submergence ensued

towards close of the period, with conditions passing from temperate to arctic.

7. UPPER BOULDER-CLAY. General *mer de glace*, confluent with that of Scandinavia ; it did not flow so far south as that of preceding glacial epoch.

8. INTERGLACIAL BEDS—(Fresh-water alluvia, peat, &c.; marine deposits). Britain probably again continental: climate at first temperate and insular; submergence ensues with cold climatic conditions—Scotland depressed for 130 ft. or thereabout.

9. GROUND-MORAINES AND TERMINAL MORAINES. Major portion of Scottish Highlands covered by ice-sheet; local ice-sheets and district glaciers in Southern Uplands of Scotland, and in mountainous parts of England, Wales, and Ireland. Icebergs are calved at mouths of Highland sea-lochs; terminal moraines dropped upon marine deposits, then forming (100-ft. beach in Scotland).

10. INTERGLACIAL BEDS—(Fresh-water alluvia with arctic plants; lower buried forest and peat; Carse-clays and raised beaches). Britain again continental; climate at first cold, subsequently becoming temperate; great forests. Eventual insulation of Britain ; climate humid, and probably colder than now.

11. MOUNTAIN-VALLEY MORAINES; CORRIE MORAINES. In Scotland these in some places rest on raised beaches (45–50 ft. above sea) ; snow-line at 2,500 ft.

12. UPPER BURIED FOREST ; ALLUVIA, &c. Re-elevation of land, to what extent is not known ; climate temperate.

13. PEAT overlying 'upper buried forest;' low-level RAISED BEACHES ; high-level CORRIE GLACIERS, snow-line at 3,500 ft. ; climate somewhat colder and more humid than now.

14. Final retreat of sea to present level ; decay of peat-bogs ; disappearance of permanent snow ; climate drier than during preceding stage (13).

CHAPTER XXIX.

GLACIAL PHENOMENA OF NORTHERN EUROPE.

Glaciation of the Scandinavian peninsula; Finland—North Germany, &c.—Glacial striæ, shattered rock-surfaces, and contorted strata under boulder-clay—'Giants' kettles' in Germany—General description of the ground-moraines of Northern Europe—The maximum glaciation—Traces of an earlier glaciation in the Baltic basin—Fossiliferous beds underlying 'lower diluvium'—Fossiliferous interglacial beds of Sweden and Denmark; of Schleswig; of Holstein; of Rügen and Bornholm; of West and East Prussia; of Mecklenburg—Physical conditions of Baltic area in interglacial times.

IF the British Islands, which are now in the enjoyment of a temperate climate, have beyond doubt experienced in ages that are past the severity of arctic and glacial conditions, it would only be reasonable to infer that other regions of the northern hemisphere should give evidence of having likewise been at the same time characterised by a rigorous climate. It is, *à priori*, in the highest degree improbable that great ice-sheets should have enveloped a large part of our country, while other areas in similar or nearly similar latitudes escaped. On the contrary, the observer who knew nothing whatever of the geological records of any country save his own would be justified in believing that the evidence gathered in Britain alone is enough to suggest that during the intense cold of the Glacial Period the temperature of the whole northern hemisphere must have been affected. Geological investigations have clearly shown that such was actually the case.

I have already had occasion to mention the great ice-sheet that covered Scandinavia, and to point out that it coalesced with that of Britain upon the floor of the North Sea. No grander display of ice-action could one wish to behold than that which the fiords and fiord-valleys of Norway present. The smoothed and mammillated mountain-slopes, the rounded islets that peer above the level of the sea like the backs of great whales, the glistening and highly-polished

faces of rock that sweep right down into deep water, the great perched blocks, ranged like sentinels on jutting points and ledges, the huge mounds of morainic débris in the valleys, and the wild disorder of crags and boulders scattered over the former paths of the glaciers, combine to make a picture which no student of physical geology is likely to forget. The whole country has been moulded, and rubbed, and polished by one immense sheet of ice, which in its deeper portions could hardly have been less than 5,000 ft. or even 6,000 ft. thick.[1]

The Gulf of Bothnia appears to have brimmed with ice, which pressed up against and even overflowed the lofty Norwegian frontier, through the valleys of which it found its way into the North Sea.[2] Dr. Törnebohm and Prof. Högbom have shown that the glacier-carried erratics of Jemtland demonstrate that the ice has passed from east to west—that is, right against the slope of the land; and, according to Keilhau, similar blocks which could only have come from Sweden are now found in Trondhjems-fiord; while Pettersen has recorded similar facts in connection with the glacial phenomena of Northern Norway.[3] The most remarkable circumstance in connection with some of these blocks consists in the fact that they occur at a considerably greater height than the rock from which they have been derived. Thus at Åreskutan, Törnebohm found blocks at a height of 4,500 ft. which could not possibly have come from any place higher than 1,800 ft.

The Scandinavian inland ice not only filled the Gulf of Bothnia, but occupied the whole area of the Baltic Sea, overflowing the Åland Isles, Gottland, Öland, Bornholm, and Denmark, passing south-east over Finland into Russia, across

[1] Mr. Amund Helland in his paper 'Om Mægtigheden af Bræerne i Norge under Istiden,' *Geologiska Föreningens i Stockholm Förhandlingar*, 1874, Band ii. No. 6, states that the height reached by the ice-scratches in the Sogne-fjord indicates a thickness of from 1,700 to 1,800 metres; in Hardanger-fjord of 1,200 metres.

[2] See Hörbye's *Observations sur les Phénomènes d'Erosion en Norvège*, where the striæ are indicated as crossing the watershed between the two countries.

[3] See Törnebohm, *Geol. Fören. Förh.* Bd. i. p. 82; xiii. p. 587; Högbom, *Sveriges Geologiska Undersökning*, Ser. C. No. 70; Pettersen, *Tromsö Museums Aarshefter*, Bd. vii. p. 1; Kjerulf, *Udsigt over det sydlige Norges Geologi*, p. 24, Plate V.; Hansen, *Om Beliggenheten av Bræskillet*, 1893.

Lake Onega, Lake Ladoga, and the Gulf of Finland,[1] traversing the Baltic coast-lands of Germany, and eventually drowning the major portion of the great Central Plain of Europe. The direction of the glaciation in the extreme north of Scandinavia, the peninsula of Kola, and north-eastern Finland, demonstrates that the great *mer de glace* radiated outwards from the high grounds of Norway and Sweden, flowing north and north-east into the Arctic Ocean and east into the White Sea, and thus clearly proving that Northern Europe was not overflowed by any vast ice-cap creeping outwards from the Pole, as was at one time supposed by Agassiz.

When we leave the rocky grounds of the Scandinavian peninsula and Finland and pass into the low-lying tracts of the great Central Plain, we enter upon a region more or less thickly covered with superficial accumulations of gravel, sand, and clay. Only at wide intervals do the underlying rocks come to the surface, and these in Denmark and North Germany consist chiefly of chalk and more or less incoherent deposits of Tertiary age. One looks in vain therefore for striated rock-surfaces under such conditions. Now and again, however, harder rocks make their appearance, as at Rüdersdorf, near Berlin. There, so far back as 1836, striæ were observed upon the surface of a limestone (*Muschelkalk*), but their occurrence does not seem to have excited much interest, until in 1875 their true significance was pointed out by the Swedish geologist, Professor Otto Torell. Since then similar rock-striæ have been detected at a number of other places, as at Osnabrück[2] (Hanover), at Velpke and Danndorf[3] (Brunswick), near Magdeburg,[4] and at a number of places in Brandenburg[5] and in the province and kingdom of Saxony.[6]

[1] Professor Nordenskjöld, *Beitrag zur Kenntniss der Schrammen in Finland* (Helsingfors, 1863) and the publications of the Geological Commission of Finland; for direction of Norwegian glaciation see Hörbye's and Kjerulf's works, *op. cit.*; for that of Sweden consult the maps and memoirs of the Geological Survey of that country.

[2] Hamm, *Zeitschr. d. deutsch. geol. Ges.* 1882, p. 629.

[3] Wahnschaffe, *op. cit.* 1880, p. 774.

[4] *Ibid. op. cit.* 1883, p. 831; Schreiber, *op. cit.* 1889, p. 604; Berendt, *op. cit.* 1890, p. 613.

[5] Laufer, *Jahrb. d. königl. preussen Landesanst.* 1880, p. 33; *Neues Jahrb. f. Min.* &c., 1881, Bd. i. p. 261; Berendt, *Zeitschr. d. deutsch. geol. Ges.* 1882, p. 658.

[6] Lüdecke, *Neues Jahrb. f. Min. Geol. u. Pal.* 1879, p. 567; Fritsch, *Zeitschr. f. Naturwiss. Halle*, iv. Folge, Bd. iii. p. 342; Credner, *Zeitschr. d.*

These glaciated surfaces and *roches moutonnées* clearly prove that the great Plain of Europe has been traversed by 'inland ice' flowing from Scandinavia and the Baltic. The striæ have a general southerly trend—some running due north and south, others being a little east or west of south as the case may be. All those met with in Saxony appear to have been the work of one and the same *mer de glace*. Farther north, however, as at Rüdersdorf (Berlin), there are two sets of striæ—one set trending towards south-south-east, the other and later series being directed towards the west.

Glaciated rocks, however, are not the only evidence of the former presence of 'inland ice' in the low plains of Europe. Wide regions, as we shall learn, are cloaked with characteristic boulder-clay, and underneath this deposit the rocks are often highly confused and disturbed, dislocated, and displaced. Instead of being smoothed and polished, they frequently show a shattered and jumbled surface. 'The boulder-clay,' as I have remarked elsewhere,[1] 'is sometimes mixed up with the shattered rock, and in places appears even to have been intruded between the strata, so as to assume the aspect of an intercalated bed.' The most remarkable example of these curious phenomena is that furnished by the north-east coast of the island of Moen in the Baltic, some account of which is given by Lyell,[2] who, following Puggaard, attributed the remarkable contortions and displacements of the Chalk to subterranean action. The cliffs reach a height in places of 400 ft., throughout which the Chalk is fissured, dislocated, and shifted—the dislocations, in which the glacial deposits partake, extending from top to bottom of the sections. Professor Johnstrup was the first to show that all this con-

deutsch. geol. Ges. 1879, p. 21; Penck, *op. cit.* 1879, p. 131; Dathe, *Neues Jahrb. f. Min. Geol. u. Pal.* 1880, Bd. i. p. 92; Hazard, *ibid.* 1891, Bd. i. p. 214; A. Schreiber, *Zeitschr. d. deutsch. geol. Ges.* 1889, p. 603. See also the publications of the Geological Survey of Saxony: Schalch, *Erlaut. z. Section Brandis*, p. 41; Dalmer, *Erlaut. z. Section Thallwitz*, p. 23, &c.; *Berichte d. Naturf. Ges. Leipzig*, 1883. For a list of all the glaciated surfaces observed in the low grounds of North Germany, see Wahnschaffe, *Die Ursachen der Oberflächengestaltung des norddeutschen Flachlandes*, 1891, p. 6.

[1] *Prehistoric Europe*, p. 200.

[2] *Antiquity of Man*, p. 388. Excellent sketch-sections of these cliffs are given by C. Puggaard (*Moens Geologie*, 1851), and by F. Johnstrup (*Bretningen om Mödet af 11te Skandinaviske Naturforskermöde i Kjöbenhavn*, 1873; *Zeitschr. d. deutsch. geol. Ges.* 1874, p. 533).

›n was the work of the 'inland ice.' Similar disturbances seen in the island of Rügen, the ground-rock of which iists, as in Moen, of chalk. They are best displayed in the cliffs of Jasmund in the north-east of the island. There, n Moen, the rocks are dislocated and disturbed along ı the glacial accumulations. According to some geologists dislocations are the result of subterranean action,[1] while ›rs attribute them to glacial action.[2] Professor Rudolph lner, in his excellent description of Rügen, has shown the dislocations in question affect the older but not the ıger glacial deposits, for while the former are shifted and 'used along with the ground-rock, the latter overspread disturbed and ruptured masses in continuous sheets. re is, in short, a marked unconformity between what are wn as the 'lower' and the 'upper diluvium.' Credner

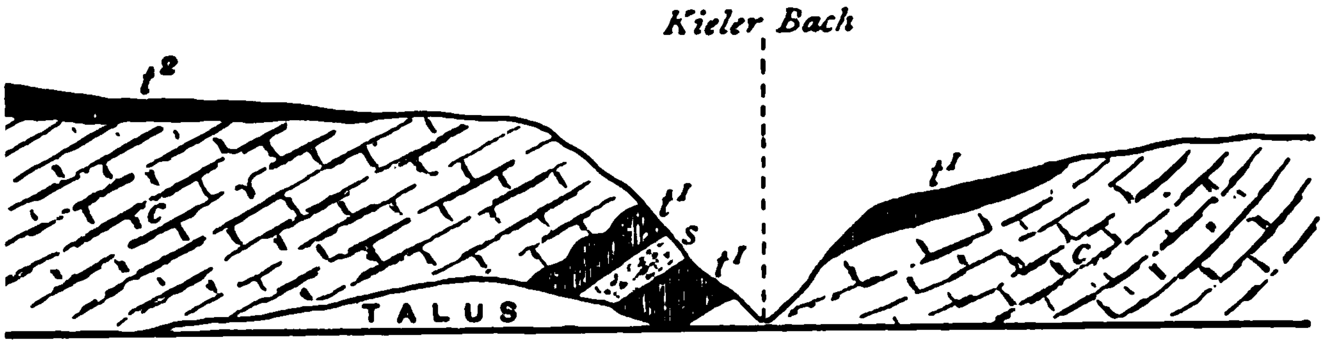

Fig. 72.—Section of Sea-cliff, Island of Rügen.
c chalk ; t^1 lower boulder-clay ; s sand ; t^2 upper boulder-clay.

efore concludes that the subterranean action, to which ›elieves all the disturbances are due, took place during rglacial times. Those who think the disturbances are result of glacial work would assign them to the push ted by the inland ice underneath which the older dilu- n was accumulated—the later ice-sheet, as we shall learn, much smaller, and therefore could not have an equally ructive effect. Having visited Rügen and studied the it-sections of Jasmund, I am able to confirm the observa- s of my predecessors. In quite a number of places lder-clay with associated sand is distinctly intercalated

See Scholz, *Jahrb. d. königl. preuss. geol. Landesanstalt f.* 1886 and ; Von Könen, *ibid.* 1886 and 1887 ; H. Credner, *Zeitschr. d. deutsch. Ges.* 1889, p. 365 ; E. Cohen and W. Deecke, *Mitteil. d. naturw. Vereins upommern und Rügen*, 1889 ; R. Credner, *Forsch. z. deutsch. Landes- und ıkunde*, Stuttgart, 1893, p. 377.

F. Johnstrup, *op. cit.* in preceding footnote, p. 426; G. Berendt, *Zeitschr. itsch. geol. Ges.* 1889, p. 147.

between underlying and overlying masses of chalk. Thus at the mouth of the Kielerbach the section given on the preceding page is clearly exhibited in the sea-cliffs.

Similar sections occur in the same coast near this place, and Professor Berendt is of opinion that the intercalation of the boulder-clay has been brought about by flexure—the chalk and overlying boulder-clay having been doubled up and folded together. Others, on the contrary, believe the position of the boulder-clay is the result of faulting. After examining the sections I could not detect any certain evidence to show that the chalk and 'diluvium' had been doubled up in the manner suggested by Berendt. Still less could I observe any trace of the dislocations which are seen in the diagrams given by Cohen and Deecke, where faults are shown cutting across the boulder-clay so as to bring it abruptly against a face of chalk. In all the sections seen by me the lower boulder-clay lay at approximately the same angle as the underlying and overlying chalk: when the dip of the chalk was high, so also was that of the boulder-clay; when the bedding was gently inclined or horizontal, the boulder-clay had a similar disposition. The opinion I formed was that the junctions between the boulder-clay and the overlying chalk are 'thrust-planes,' and I agree with Berendt that the disturbances are due to the pressure and drag of an ice-sheet. That the inland ice which formed the lower boulder-clay of Rügen was capable of producing such local displacement is shown by the fact that the boulder-clay in question contains in places enormous erratics, amongst which are great tabular masses of chalk—comparable to the similar large erratics in the 'contorted drift' of Cromer. Further, the stratification of the chalk of Rügen is often greatly confused—the flint nodules, originally arranged in parallel layers, being chaotically kneaded and mixed up with the chalk. The whole complex, in short, is strongly suggestive of glacial work.[1]

[1] Professor R. Credner attributes the fracturing and displacement of the chalk and lower boulder-clay to 'earth-movements,' similar to those which have originated the complicated structures of mountain-chains, and thinks that the dislocations in Rügen show certain determinate trends. These he gives as follows:—(*a*) SSE.-NNW. with deflections to N.-S.; (*b*) E.-W. with deflections to ESE.-WNW.; (*c*) NE.-SW. with deflections to ENE.-WSW. Under the drag of an ice-sheet flowing in one determinate direction, rocks that yielded to the

Similar disturbances affect the Tertiary deposits in Hol- 1 as at Itzehoe,[1] and chalk erratics of very large dimen- s occur in the 'diluvium' of the same country. Thus hns describes one in East Holstein which measured t. in length, 10 ft. in breadth, and 12½ ft. in thickness. in, in Mecklenburg-Schwerin so large are some of the lk erratics that they have been mistaken for protruding of the rock *in situ*.[2] Even harder and more resisting ;s than chalk are occasionally seen in a confused and tered condition under the boulder-clay. Thus at Rüders- limestone is found showing in places a smooth and ted surface, while in other places it is shattered and 1 crushed and folded.[3] Professor H. Credner has like- noticed in Saxony that greywacké[4] shows now and in a similar disturbed appearance below boulder-clay,[5] the same fact has been observed by A. Sauer.[6] It may

ure would doubtless be folded and fractured and displaced according to a in system. Along the east coast of Jasmund all the thrust-planes I saw general SE. and NW. strike—and this is just what one might have expected, g that the ice-flow came approximately from NE. But not one of these t-planes can be traced inland beyond the section in which it is actually sed; nor could it be shown that the amount of displacement in any case ded that which has been observed in other places as certainly the result of ction. To determine the precise direction of a system of tectonic disloca- , one must trace individual faults across a district. But this cannot be in Rügen, which is more or less thickly covered with 'diluvial' deposits. dislocations referred to by Credner are exposed at intervals only in pits, , &c., and, as every field geologist will admit, it is impossible to infer the se direction of a fault from a single isolated section. If we could peel the covering from Rügen, I believe we should find that the three systems of s described by Credner all belong to one and the same system, which would a general SE. and NW. trend.

Haas, *Mitteil. aus dem mineralogischen Institut der Universität Kiel*, . Hft. i.

On the coast of Mecklenburg near Warnemünde fine examples of contorted al deposits are exposed. (Geinitz, *VI. Beitrag zur Geologie Mecklenburgs*,) Farther east, at Finkenwalde near Stettin (Pomerania), the Tertiary and ceous strata are similarly much disturbed and confused. (G. Berendt, *chr. d. deutsch. geol. Ges.* 1884, p. 866.) The various geologists referred ove recognise these disturbances as due to the action of the inland ice. phenomena themselves, however, had been familiar to continental geolo- long before their origin was understood, and excellent descriptions of them t be cited from works written nearly half a century ago, such as those by aard, already referred to, the account of the lignite-deposits of Brandenburg ettner, as well as in works by Girard, Glocker, and others.

Penck, *Zeitschr. d. deutsch. geol. Ges.* 1879, p. 133; Wahnschaffe, *Jahrb. nigl. preuss. geol. Landesanstalt f.* 1882, p. 219.

The somewhat hard bluish grey rock, of which such hills as those of the ish Southern Uplands and the Cumbrian and Welsh mountains are princi- composed.

Zeitschr. d. deutsch. geol. Ges. 1880, p. 77.

Ber. d. naturforsch. Ges. in Leipzig, 1881, p. 12.

be added that the Silurian rocks of the Baltic provinces of Russia also afford like evidence of disturbance by the inland ice.[1] In all the cases referred to the underlying rocks are bent over in the direction followed by the ice—their débris being included in the lower portion of the superjacent till. In other places, where the bottom rocks consist of Tertiary strata—clay, sand, lignite, &c.—the folding and displacement effected by the ice-sheet are often on a large scale. Professor H. Credner has described[2] many remarkable examples in Saxony where the Brown Coal formation is often confusedly mixed up with boulder-clay. The Tertiary strata are folded, crumpled, and contorted, and have been subjected to such intense pressure that long tongues and wedges have been squeezed and dragged into the heart of the boulder-clay. Helland also refers to these disturbances, and mentions that wide stretches of the Brown Coal formation have been forced out of place, and now appear intercalated with the boulder-clay, as if they formed part of one and the same series, in which position they have actually been mined.[3] Similar phenomena, as already mentioned, have been observed by H. J. Haas in Schleswig-Holstein, and by Jäkel in Northern Silesia, where coal-bearing Tertiary beds are abruptly folded and ruptured under the boulder-clay of that region.[4] It goes without saying that the clays, sands, and gravel associated with the till exhibit similar appearances of disturbance, as Credner, E. Geinitz, Wahnschaffe, and others have again and again pointed out.[5]

Additional remarkable evidence of the former appearance of a great ice-sheet in the plains of Germany is furnished by the presence of what are called 'Giants' Kettles.' These are well known in the valleys of Norway[6] and the Alps, and

[1] Schmidt, *Zeitschr. d. deutsch. geol. Ges.*, 1884, p. 126.
[2] *Zeitschr. d. deutsch. geol. Ges.*, 1880, p. 75.
[3] *Ibid.* 1879, p. 72
[4] *Ibid.* Bd. xxxix. p. 298.
[5] The reader will find an excellent account of these and other disturbances produced by the forward movement of the ice-sheet, with copious references to the literature of the subject, in Wahnschaffe's interesting work already cited, *Die Ursachen d. Oberflächengestaltung d. norddeutsch. Flachlandes*, p. 72. It will be understood that similar phenomena characterise the glacial accumulations of Scandinavia and other parts of Northern Europe. See, for example, E. Erdmann's papers on the superficial deposits of Scania (*Geol. För. i Stockholm Förh.* Bd. i. p. 210; ii. pp. 13, 101; vi. p. 425).
[6] S. A. Sexe, *Universitets-Program for 1te Semester*, 1874; W. C. Brögger

simply large pot-holes formed on the bed of a glacier by ter plunging down through crevasses. The *moulins*, as h water-drills are called, set stones and boulders in rapid ation, and thus in time more or less deep depressions are lowed out upon the bed of the glacier. Everyone who visited the Glacier Garden at Lucerne will remember fine display of 'kettles' seen there. The accompanying ire is a section of a Norwegian 'giant's kettle,' filled h rolled stones and boulders.

Now kettles of this kind have been described by Noetling,[1] rendt,[2] Penck,[3] E. Geinitz,[4] H. Gruner,[5] E. Laufer,[6] Zeise,[7] and others in various parts of North Germany. me of the examples occur in limestone, sandstone, and ier rocks, while not a few pear in the diluvial deposits mselves. Frequently the tles seem to be arranged ng well-marked hollows of surface; at other times y occur quite sporadically, pearing here and there as upt depressions in an other- e level country. While re may be some doubt ether these last have always n excavated by water in way supposed, there can none as to the origin of the giants' kettles that occur in estone and other relatively hard rocks.

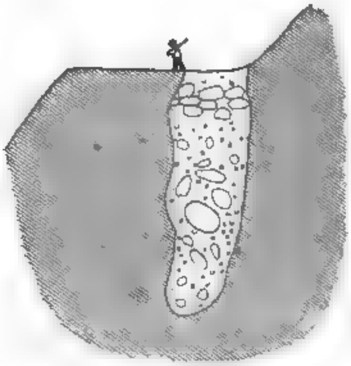

Fig. 78. Giant's Kettle: filled with boulders, gravel, &c.

H. H. Reusch, *Quart. Journ. Geol. Soc.* 1874, vol. xxx. p. 750; H. H. sch, *Nyt. Mag. for Naturvidensk.* 1876, p. 169. They occur frequently in Finland and the Baltic provinces of Russia. See, for example, G. von lmersen, *Mém. d. l'Acad. Imp. d. Sc. d. St-Pétersbourg*, vii^e Sér. t. xi. No. ; *Zeitschr. d. deutsch. geol. Ges.* 1880, p. 631; C. Grewingk, *Sitzungsber. d. rpater Naturf. Ges.* 1886.

[1] *Zeitschr. d. deutsch. geol. Ges.* Bd. xxxi. 1879, p. 339.

[2] *Ibid.* 1880, p. 56; *Neues Jahrb. f. Min. Pal. u. Geol.* 1879, p. 851; 1881, ii. p. 121.

[3] *Zeitschr. d. deutsch. geol. Ges.* 1879, p. 617.

[4] 'Beitrag zur Geologie Mecklenburgs' (*Arch. d. Ver. d. Freunde d. turgesch. in Mecklenburg*), I. 1879, p. 54; II. 1880, p. 10; VI. 1884, p. 4. See o the same author's elaborate work, *Die Seen, Moore und Flussläufe Mecklen- rgs*, Güstrow, 1886.

[5] *Zeitschr. d. deutsch. geol. Ges.* 1880, p. 183.

[6] *Ibid.* 1883 (Bd. xxxv.), p. 623.

[7] *Ibid.* 1887 (Bd. xxxix.), p. 513.

Boulder-clay, with associated sand and gravel, has been traced over a vast area in Northern Europe. It is of course quite impossible to give a particular account of these deposits, but this is the less necessary since they exactly resemble in all important particulars the similar accumulations met with in the British Islands. As a rule the boulder-clay appears as wide sheet-like masses with a gently undulating surface. In some regions, as in the Baltic coast-lands of North Germany, it forms enormous plains, the surface of which now and again rises with a long swell for a few feet or yards above the general level. In other districts these swellings and undulations are more prominent and abundant, but the long parallel banks which are known in our country as drums and drumlins appear to be of infrequent occurrence. The only place in which I have seen them is the island of Rügen in the Baltic, where they have been mapped by Professor Rudolf Credner. In that region the drums frequently have a nucleus of rock (chalk). Sand and gravel, as in Britain, are often associated with the boulder-clay.

For many years it was believed that all those superficial deposits were of iceberg origin. The low grounds of Northern Europe were supposed to have been submerged at a time when numerous icebergs, detached from glaciers in Scandinavia and Finland, sailed across the drowned countries, dropping rock-rubbish on the way. Such was thought to have been the origin of the erratics, stony clay, and other superficial accumulations, and hence they came to be known as the 'great northern drift formation.' By-and-by, however, the true morainic character of the stony clays of the low grounds of Norway, Sweden, and Finland was recognised. But for some years longer geologists continued to maintain that the 'drifts' of Northern Germany, &c., had been deposited in the sea. When we come to study these drifts it is not hard to see why they should have been thought to have had a marine origin. They present certain features, which although not absent from the glacial deposits of the northern hilly regions, are yet not nearly so characteristic of such upland tracts. I refer especially to the frequent interstratification of boulder-clays with well-bedded deposits of clay, sand, and gravel; and to the fact that these boulder-

clays are sometimes less compressed than those of Sweden and Finland, and have even occasionally a somewhat silt-like character. Such appearances do seem at first to be readily explained on the assumption that the deposits have been accumulated in water opposite the margin of a continental glacier or ice-sheet—and this was the view which several accomplished geologists in Germany were for some time inclined to support. But when the phenomena came to be studied in greater detail and over a wider area, this explanation did not prove satisfactory. The facts described in the preceding paragraphs—the occurrence of striated surfaces and *roches moutonnées*, the disturbed appearances associated with the till, and the not infrequent presence of giants' kettles—convinced geologists that all the vast regions over which boulder-clay is distributed were formerly occupied by the 'inland ice' of Scandinavia.

No evidence of marine action in the formation of the stony clays is forthcoming—not a trace of any sea-beach has been detected. And yet, if these clays had been laid down in the sea during the retreat of an ice-sheet from Germany, surely such evidence as I have indicated ought to be met with. To the best of my knowledge, the only particular facts which have been appealed to, as proofs of marine action, are the appearance of bedded deposits in the boulder-clays, and the occasional occurrence in the clays themselves of a sea-shell. But other organic remains are also met with now and again in similar positions, such as mammalian bones and fresh-water shells. All these, however, have been shown to be derivative in their origin—they are just as much erratics as the stones and boulders with which they are associated. The only phenomena, therefore, that the glacialist has to account for are the bedded deposits which occur so frequently in the boulder-clays of the peripheral regions, and the occasional silty and uncompressed character of the clays themselves.

The intercalated beds are, after all, not hard to explain. If we consider for a moment the geographical distribution of the boulder-clays, and their associated aqueous deposits, we shall find a clue to their origin. Speaking in general terms, the stony clays thicken out as they are followed from the mountainous and high-lying tracts to the low grounds. Thus

they are of inconsiderable thickness in Norway, the higher parts of Sweden, and in Finland, just as we find is the case in Scotland, Northern England, Wales, and the hilly parts of Ireland. Traced south from the uplands of Scandinavia and Finland, they gradually thicken out as the low-grounds are approached. Thus in Southern Sweden they reach a thickness of 43 metres or thereabout, and of 80 metres in the northern parts of Prussia, while over the wide low-lying regions to the south they attain a much greater thickness—reaching now and again in Holstein, Mecklenburg, Pomerania, and West Prussia a depth of 100 to 130 metres, and still greater depths in Hanover, Mark Brandenburg, and Saxony.[1] In those regions, however, a considerable portion of the 'diluvium' consists, as we shall see presently, of water-formed beds.

The geographical distribution of the aqueous deposits which are associated with the stony clays is somewhat similar. They are very sparingly developed in districts where the boulder-clays are thin. Thus they are either wanting, or only occur sporadically in thin irregular beds, in the high grounds of Northern Europe generally. Farther south, however, they gradually acquire more importance, until in the peripheral regions of the drift-covered tracts they come to equal and eventually to surpass the boulder-clays in prominence. These latter, in fact, at last cease to appear, and the whole bulk of the 'northern drift formation' along its southern margin appears to consist of aqueous accumulations alone.

The explanations of these facts advanced by German geologists are quite in accordance with the views which have long been held by glacialists elsewhere, and have been tersely summed up by Dr. Jentzsch.[2] The northern regions, he says, were the feeding-grounds of the inland ice. In those regions melting was at a minimum, while the grinding action of the ice was most effective. Here, therefore, erosion reached

[1] The greatest thickness hitherto observed is at Strasburg (Uckermark), where a boring reached a depth from the surface of 204 metres without touching the bottom of the glacial series. F. E. Geinitz, XI. *Beitrag zur Geologie Mecklenburgs*, 1890. A record of all the deep borings in the low grounds of North Germany is given by Dr. Wahnschaffe in his interesting work on the origin of the surface-features of those regions, *Forschungen zur deutsch. Landes- u. Volkskunde, &c.* Bd. vi. p. 21.

[2] *Jahrb. d. königl. preuss. geologischen Landesanstalt für* 1884, p. 438.

its maximum—ground-moraine or boulder-clay being unable to accumulate to any thickness. Farther south melting greatly increased, while ground-moraine at the same time tended to accumulate—the conjoint action of glacier-ice and subglacial water resulting in the complex drifts of the peripheral area. In the disposition and appearance of the aqueous deposits of the formation we have evidence of an extensive subglacial water-circulation—glacier-mills that gave rise to 'giants' kettles'—chains of subglacial lakes in which fine clays gathered—streams and rivers that flowed in tunnels under the ice, and whose courses were paved with sand and gravel. Nowhere do German geologists find any evidence of marine action. On the contrary, the dove-tailing and interosculation of boulder-clay with aqueous deposits are explained by the relation of the ice to the surface over which it flowed. Throughout the peripheral area it did not rest so continuously upon the ground as was the case in the inner region of maximum erosion. In many places it was tunnelled by rapid streams and rivers, and here and there it arched over subglacial lakes, so that accumulation of ground-moraine proceeded side by side with the formation of aqueous sediments. Much of that ground-moraine is of the usual tough and hard-pressed character, but here and there it is somewhat less coherent and even silt-like. Now a study of the ground-moraines of modern glaciers affords us a reasonable explanation of such differences. Dr. Brückner[1] has shown that in many places the ground-moraine of Alpine glaciers is included in the bottom of the ice itself. The ground-moraine, he says, frequently appears as an ice-stratum abundantly impregnated with silt and rock-fragments—it is like a conglomerate or breccia which has ice for its binding material. When this ground-moraine melts out of the ice—no running water being present—it forms a layer of unstratified silt or clay, with stones scattered irregularly through it. Such being the case in modern glaciers, we can hardly doubt that over the peripheral areas occupied by the old northern ice-sheet boulder-clay must frequently have been accumulated in the same way. Nay, when the ground-moraine melted out and dropped here

[1] 'Die Vergletscherung des Salzachgebietes,' &c., *Geographische Abhandlungen, herausgegeben v. A. Penck*, Bd. i. Heft 1.

and there into quietly-flowing water it might even acquire in part a bedded character.

Hitherto I have spoken of boulder-clay as if only one deposit of the kind occurred in the regions of the great 'northern drift.' In various countries, however, two boulder-clays are recognised, and in the Baltic provinces of Germany three or even four separate sheets of till have been observed. The boulder-clay which has the widest extension in Northern Europe belongs to the lower division of the glacial formation or 'diluvium,'[1] as it is generally termed on the Continent. This 'lower diluvium' is believed to have been laid down during the climax of glacial cold, when the inland ice attained its greatest development. The limits reached by that vast *mer de glace* are becoming more and more clearly defined, although its southern margin will never be so accurately determined as that underneath which the youngest boulder-clay of the Baltic coast-lands was accumulated. The reasons for this are obvious.

When the inland ice flowed south to the Harz and the hills of Saxony it formed no correspondingly great terminal moraines. Doubtless many erratics and much rock-rubbish were showered upon its surface from the higher mountains of Scandinavia, but owing to the fanning-out of the *mer de glace* on its southward march such superficial débris was necessarily spread over a constantly widening area.[2] It may well be doubted, therefore, whether it ever reached the terminal front of the ice-sheet in sufficient bulk to form con spicuous moraines.[3] It seems most probable that the termina

[1] This term is a 'survival,' and was applied to the deposits when the were generally supposed to be the result of vast débâcles or floods, or of t Noachian deluge. It is convenient to have some such term to include bo boulder-clay and the aqueous deposits associated with it. A better word mig be chosen were the deposits being described for the first time, but 'diluviu is not likely to be superseded now.

[2] I do not agree with those who suppose that much morainic material (*in glacial moraine*) could have been included in the heart of the inland ice ' occupied the low plains of Northern Europe. It is probable that quantiti rock-débris became enclosed in the upper parts of the ice in the mou regions of Scandinavia, but as the inland ice fanned out southwards, such i glacial materials must have formed an insignificant proportion of the mo accumulations. The ice of the old *mer de glace* of Europe was probably a and free from inclusions as that of polar regions in our own day.

[3] Such terminal moraines, however, are occasionally conspicuous e as, for example, at Taucha and Dahlem near Leipzig, where certai marked hills and ridges of gravel and sand, composed largely of n

EURO

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Plate IX.

Engr.d Knight London

moraines of the great inland ice would consist of low banks of boulder-clay and hillocks and hummocks of sand and gravel or 'kames'—the latter, perhaps, strongly predominating, and containing here and there larger and smaller angular erratics which had travelled on the surface of the ice. However that may be, it is certain that the whole region in question has been considerably modified by subsequent denudation, and to a large extent is now concealed under deposits belonging to later stages of the Pleistocene period. The extreme limits reached by the ice are determined rather by the occasional presence of rock-striæ and *roches moutonnées*, of boulder-clay, northern erratics, and gravel and sand of northern materials in sheets or in mounds, than by recognisable terminal moraines. The southern limits reached by the old inland ice appear in this way to have been tolerably well ascertained over a considerable portion of Central and North-east Europe, and is shown on the map (Plate IX.). Partly, by means of rock-striæ and *roches moutonnées*, &c., but chiefly by the direction of transport of erratics, geologists have been able to track the general course followed by the ice-sheet. The reader will obtain from the map (Plate IX.), however, a better notion of the ice-flow than can be conveyed by verbal description. It will be seen that the ice radiated outwards from Scandinavia, moving across the great plains of Europe into Southern Belgium, and to the foot-slopes of the hills of Middle Germany—the Harz, the Erzgebirge, the Sudetes, &c., and extending south-east and east over a vast region in Russia. The limits reached by the *mer de glace* in Belgium are indicated approximately by the presence of Scandinavian erratics.[1] The occurrence of similar erratics in 'diluvium' in the neighbourhood of Detmold and Herford, shows that the ice-sheet crossed the Weser Hills, but did not quite

materials, were recognised by Professor H. Credner as of the same character and origin as the kames of Scotland (*Zeitschr. d. deutsch. geol. Ges.* Bd. xxxii. (1880) p. 588). Dr. Mehnert has likewise recorded the occurrence of terminal moraines at Lohmen and Uttewalde in Saxony ('Ueber Glacialerscheinungen im Elbsandsteingebiete,' *Inaugural Dissertation*, 1888). They have been observed also in the neighbourhood of Cracow in Poland (Siemiradski, *Zeitschr. d. deutsch. geol. Ges.* Bd. xlii. (1890) p. 756).

[1] E. Delvaux, *Ann. Soc. Géol. de Belgique*, t. xi. (1883–84) pp. 52, cii; t. xiii. (1885–86) p. 158; t. xiv. (1887–88) pp. 97, 117; *Ann. Soc. Roy. Malac. de Belgique* (1885) t. xx. p. 6; E. Vanden Broeck, *Ann. Soc. géol. du Nord*, t. xi. p. 2.

reach the Teutoburg Forest.[1] Boulder-clay with northern stones occurs at Seesen and Gandersheim at the foot of the Harz,[2] and morainic débris and travelled blocks are stranded on the same mountains up to a height of 400 metres, according to Lossen, while in Saxony, west and east of the Elbe, they have been met with by H. Credner, A. Jentzsch, and F. E. Geinitz at 400, 407, and 415 metres. In the Riesengebirge their occurrence at 400 to 426 metres has been noted by R. Schottky, and they have been traced in the Sudetes by Orth, Bocksch, and C. von Camerlander up to 400 to 439 and 441 metres, while in Moravia they have been observed at a similar height by F. Römer.[3] The presence of the ice-sheet along the base of these mountain-ranges must have greatly modified the drainage in their lower valleys, damming these up in some cases, and thus forming glacial lakes. Dr. Schottky has shown that such was the case with the broad Hirschberg valley in the Riesengebirge. The limits attained by the *mer de glace* in Russia are approximately indicated, as in Belgium, by the presence of erratics. The general results obtained by himself and other Russian geologists have been tabulated by M. S. Nikitin,[4] and are

[1] O. Weerth, *Zeitschr. d. deutsch. geol. Ges.* Bd. xxxiii. p. 465.

[2] Von Koenen, *ibid.* Bd. xxxv. p. 622.

[3] See A. Helland, *Zeitschr. d. deutsch. geol. Ges.* 1879, p. 75; *Archiv for Mathematik og Naturvidenskab*, 1879, p. 296; H. Credner, *Zeitschr. d. deutsch. Ges.* 1880, p. 578; F. E. Geinitz, *ibid.* 1881, p. 565; Schottky, *Beiträge zur Kenntniss der Diluvial-Ablagerungen des Hirschberger Thales*, 1885; C. v. Camerlander, *Verh. d. k. k. geol. Reichsanstalt*, 1891, p. 226; A. Slavik, *Sitzungsber. d. kgl. böhm. Ges. d. Wiss. Prag*, 1891, p. 231. Taking the average height of the ice-shed in Scandinavia as 7,000 ft. and 1,350 ft. as approximately the elevation it attained upon the foot-slopes of the Harz, some 530 miles south of the ice-shed, we get an inclination for the surface of the ice of very nearly 10 ft. 8 ins. per mile. In Southern Jutland, about midway between those two points, the surface of the ice would be 2,825 ft. high, which after deducting the height of the land (about 300 ft.) would give a thickness in round numbers of 2,500 ft. for the ice that overlay Denmark. Farther east, a line drawn from the site of the Scandinavian ice-shed to the foot-slopes of the Riesengebirge measures roughly about 700 miles. Taking 1,300 ft. as the height of the inland ice in the last-named region, we get an inclination for the surface of little more than 8 ft. per mile, and a thickness of 2,900 ft. for the ice in the extreme south of Sweden, and of 1,300 ft. or thereabout for the ice in the neighbourhood of Berlin. For simplicity's sake I have considered the surface of the inland ice as sloping persistently outwards at the same angle. It is probable, however, that as the ice-flow approached its termination the angle of inclination considerably increased. The rough estimates of the thickness given are therefore probably under rather than over the mark.

[4] *Petermanns Mitteilungen*, Bd. xxxii. (1886) p. 257; *Jahrb. d. k. k. geol. Reichsanstalt*, Bd. xl. (1890) p. 51.

shown also upon the geological map recently issued by the Comité Géologique. From these sources we learn that in the far north-east the ice-sheet terminated at the foot of the Timan Mountains. From these mountains, however, confluent glaciers flowed east and north-east into the valley of the Petschora, where they were joined by similar glaciers coming from the Northern Urals ; so that this broad valley was filled with ice that crept northwards to the Arctic Sea. There is good evidence also to show that from the Urals large ice-streams flowed east and north-east into the valley of the Obi.

The ground-moraine of the great Scandinavian *mer de glace* forms the chief member of what is known to the geologists of Northern Europe as the 'lower diluvium.' Until recently it was believed to be the oldest moraine of the kind, but a few years ago Dr. A. G. Nathorst showed that a great Baltic glacier must have existed before the advent of the vast *mer de glace* underneath which the lower boulder-clay of Germany, &c., was accumulated [1] and Nathorst's observations have been confirmed and extended by H. Lundbohm.[2] The facts set forth by them prove that this Baltic glacier smoothed and striated the rocks in Southern Sweden in a direction from south-east to north-west, and accumulated a bottom-moraine whose included erratics yield equally cogent evidence as to the trend of glaciation. That old ground-moraine is overlaid by the ground-moraine of a younger *mer de glace* which flowed from NNE. to SSW., or nearly at right angles to the trend of the earlier Baltic glacier. It is difficult to avoid the conclusion that we have here to do with the products of two distinct ice-epochs. But hitherto no interglacial deposits have been detected between the boulder-clays in question. It might, therefore, be held that the earlier Baltic glacier was separated by no long interval of time from the succeeding greater *mer de glace*, but was merely a stage in the development of the latter. It is at all events conceivable that before the great *mer de glace* attained its maximum extension, it might have existed for a time as a large Baltic glacier. But,

[1] *Sveriges Geologiska Undersökning*, Ser. Aa. Nr. 87.
[2] *Geolog. Förening. i Stockholm Förhandl.* Bd. x. p. 157 ; *Sveriges Geolog. Undersökning, Afh. och Upps.* Ser. C. No. 95, 1888.

as I shall point out presently, after the *mer de glace* in question had melted away it was followed by a long epoch of genial temperate conditions, and these again were succeeded by another Baltic glacier which flowed approximately in the same direction as that followed by the earlier one. Now if no interglacial beds had been discovered between the ground-moraine of the first general *mer de glace* and that of the succeeding ice-sheet, geologists would probably have considered that the latter was simply the attenuated descendant of its predecessor.

The lower boulder-clay of Northern Europe usually lies in Norway, Northern Sweden, and Finland, upon a polished and striated rock-surface, but in the low coast-lands of the Baltic, and in the great plain of Germany, &c., it is often underlaid by more or less thick accumulations of sand and gravel, and now and again by beds of stoneless clay. There can be little doubt that these beds resemble in their origin the dreary wastes of gravel and sand (*Sandr*) in Iceland, which Helland[1] and Keilhack[2] describe as spread out by the water that escapes from the glaciers and icefields of that country. Such fluvio-glacial deposits, however, are not the only accumulations that occur in places under the so-called 'lower boulder-clay.' I use the term 'so-called' advisedly, because it may be doubted whether the 'lower boulder-clay' of one region is always the equivalent of the lower boulder-clay of other districts. Indeed, as I shall endeavour to show, it is in the highest degree probable that the lower boulder-clay of the Baltic coast-lands is the equivalent not of the 'lower' but of the 'upper' boulder-clay of Middle and Western Germany. The use of the terms 'lower' and 'upper,' however natural it may seem to be, has in my opinion only tended to confusion, and prevented the recognition of the fact that there are more boulder-clays than two. Be that as it may, however, I shall for the present follow continental geologists in their classification. When a résumé of their observations has been given it will be necessary to point out that these cannot be accounted for on the supposition that there have been only two epochs of glaciation.

[1] *Archiv for Mathematik og Naturvidenskab*, 1882.
[2] *Jahrb. d. königl. preuss. geol. Landesanst. f.* 1883, p. 160.

Under what is considered to be the 'lower boulder-clay' of the low-lying Baltic coast-lands of East Prussia, as at Steinort, Reimannsfelde, Lenzen, Succase, and Tolkemit (all on the Frische Haff), there occur certain bedded clays which have yielded arctic and boreal shells (*Yoldia arctica*, *Astarte borealis*, *Cyprina islandica*), the arctic seal (*Pagophilus groenlandicus*), a cetacean (*Delphinus*, sp.), and an undetermined form of fish, one of the Gadidæ (cod family). Closely associated with these marine clays are fresh-water beds with shells (*Dreissena polymorpha*, *Valvata piscinalis*, *Unio*, sp.), mammalian remains (*Canis familiaris*, var. *groenlandica*, *Ursus*, sp., *Elephas*, sp., *Bos*, sp., *Bison*, sp., *Cervus tarandus*, *Cervus*, sp., *Rhinoceros*, sp., *Equus*, sp.), diatoms, and quantities of wood (species not determined but both coniferous and dicotyledonous).[1] Fossiliferous clays occupying a similar position have been detected likewise in Denmark and the west of Holstein,[2] but nowhere else in Northern Europe are they known with certainty to occur.[3] The Holstein beds (at Burg in Ditmarschen) contain the following molluscan species:—*Mytilus edulis*, *Nucula nucleus*, *Leda pernula*, *Cardium edule*, *C. fasciatum*, *Cyprina islandica*, *Astarte borealis* (?), *Axinus flexuosus*, *Tellina balthica*, *Saxicava arctica*, *Natica groenlandica*, *Littorina littorea*, *Hydrobia*

[1] For descriptions of these beds see Berendt, *Schriften d. physik-ökonom. Ges. z. Königsberg*, 1868, p. 131; *Zeitschr. d. deutsch. geol. Ges.* Bd. xxxi. p. 692; Jentzsch, *Schriften d. physik-ökonom. Ges. z. Königsberg*, 1876, p. 139; *ibid.* 1882, p. 757; *Neues Jahrb. f. Min. Geol. u. Pal.* 1876, p. 738; *Jahrb. d. königl. preuss. geol. Landesanst. f.* 1885, p. lxxxviii.; *Zeitschr. d. deutsch. geol. Ges.* 1884, 1887; *Schrift. d. naturf. Ges. z. Danzig, N. F.* Bd. vii. Heft 1; *Chronologische Uebersicht der im Provinzialmuseum d. phys.-ökonom. Ges. ausgestellten geolog. Sammlungen*, 1890; Penck, *Zeitschr. d. deutsch. geol. Ges.* 1879, p. 161; *Prehistoric Europe*, p. 281; Schirmacher, 'Die diluvialen Wirbelthierreste d. Provinzen Ost- u. West- Preussen,' *Inaugural Dissertation, Albertus-Universität z. Königsberg*, 1882.

[2] Forchhammer, *Vidensk. Selskabs naturv. Afh.* Bd. ix. p. xxi.; *Oversigt o. d. kgl. danske Vidensk. Selsk. Förhandl.* 1842, p. 64; Zeise, *Mittheil. aus d. mineralog. Inst. d. Univers. Kiel*, Bd. i. Heft i. p. 79. See also for a general discussion of the evidence bearing on the history of the Baltic Sea in Quaternary times, H. Munthe, *Bihang till k. Svenska Vet.-Akad. Handlingar*, Bd. 18, Afd. ii. No. 1.

[3] In Scania (S. Sweden) a considerable thickness of clay and sand (undre hvitåbildningarna) underlies the lower boulder-clay of that region. These beds may be marine, but they have not yet yielded unequivocal traces of a marine origin. Gottsche mentions the occurrence in the island of Alsen of a thin sand, containing fresh-water shells, such as *Valvata*, *Pisidium*, and *Anodonta*, which occupies a so-called 'preglacial position.' *Sedimentärgeschiebe Schleswig-Holsteins*, p. 4.

ulvæ, and *Turritella terebra*.[1] The height at which these beds occur (16 ft. above the sea) and the character of the fauna indicate a former submergence of at least 130 ft. In the Baltic coast-lands the marine clays on the same geological horizon reach an elevation of some 230 ft. It would seem, then, that before the deposition of the 'lower boulder-clay' of those regions the Baltic Sea had open communication with the German Ocean. Some geologists have supposed that the arctic fauna of the East Prussian clay-beds may have immigrated from the north rather than from the west. But there is no direct evidence that the lands lying between the Baltic and the White Sea were under water during the formation of the shell-beds in question. We know, however, that the Cimbric peninsula was largely submerged, and it seems highly probable therefore that the arctic forms invaded the South Baltic directly from the North Sea. At the same time it may very well be that the Baltic also communicated across Northern Russia with the Arctic Ocean. Of this, however, we have at present no evidence.

The fauna of the shell-beds underlying the 'lower boulder-clay' is somewhat mixed—species with a southern range being commingled with true arctic forms. According to Munthe, the percentage of the former in the beds of West Holstein is 14—the arctic species being in the proportion of 36, while those having a wider range north and south equal 50 per cent. of the whole. Torell and others have suggested that the temperate species are relics of the fauna which occupied the Baltic area before the immigration of the arctic forms had taken place, which seems likely enough. The precise position of the shell-beds in the glacial series thus becomes an important question. From their occurrence underneath the 'lower boulder-clay' some geologists would assign them to a preglacial horizon. Dr. Jentzsch, on the other hand, more cautiously regards them as 'early glacial' (*Frühglacial*). So far as their marine organic remains are concerned, the beds might be relegated to almost any stage of the glacial series, while, unfortunately, the mammalian

[1] One may note here that the oyster is absent from all the so-called 'preglacial beds' of the Baltic coast-lands. It is quite common, as we shall see, in the interglacial beds of the same regions. (Dr. Zeise, *Mittheil. aus dem mineralog. Institut d. Univers. Kiel*, Bd. i. p. 87.)

forms obtained from the associated fresh-water layers are for the most part specifically undetermined, and therefore throw little or no light upon the question. It is worthy of note, however, that one of the fresh-water shells (*Dreissena polymorpha*) is not known to occur in any of the later interglacial or postglacial deposits of the Baltic area.[1] Obviously all that can be said of these 'early glacial' shell-beds is that they are older than the 'lower boulder-clay' that overlies them. Whether this is really on the same horizon as the ground-moraine of the great *mer de glace* that flowed south into Saxony is another matter. A number of years ago Dr. Penck pointed out that the shelly clays in question contained many small fragments of northern rocks, such as bits of Silurian from Gothland, and fragments of felspathic and crystalline rocks.[2] These, he thought, could only have been derived from some pre-existing boulder-clay, and therefore he inferred that the shell-beds really occupied an interglacial position. Indeed all the so-called 'preglacial beds' of Northern Europe are admittedly underlaid by sand, clay, &c., of 'diluvial' character; while in none of them have we any trace either of a preglacial flora or fauna. No Pliocene deposits have yet been detected anywhere in North Germany or the Baltic coast-lands, and no evidence of their former existence is forthcoming from the 'diluvial accumulations.' But the further discussion of this question must be deferred for the present.

If we are in doubt as to whether the 'lower boulder-clay' of the Baltic coast-lands really occupies the position assigned to it by German geologists generally, we can be in none as to the geological horizon of the lower boulder-clay of Western and Middle Germany (Hanover, the Province of Saxony, and Brandenburg). This boulder-clay unquestionably represents the bottom-moraine of the *mer de glace* that marked

[1] Dr. Jentzsch draws attention to the fact that *Dreissena polymorpha* is not only a living East-European form, but that it was associated in diluvial times with *Paludina diluviana*, formerly supposed to be extinct. Both forms, however, are now living in the Dobrudscha, where also *Lithoglyphus naticoides*, Fer., occurs. The latter is found associated with *Paludina diluviana* in the diluvial deposits near Berlin, and has within the last century migrated back to North Germany, as has *Dreissena* also. See Gottsche, *Sitzungs-Ber. d. Ges. naturf. Freunde zu Berlin*, 1886, No. 5, p. 74; *Zeitschr. d. deutsch. geol. Ges.* Bd. xxxviii. p. 470; Wahnschaffe, *ibid.* for 1893, p. 288.

[2] *Zeitschr. d. deutsch. geol. Ges.* 1879, p. 164.

the climax of the glacial period. It is interesting therefore to know that underneath it fresh-water deposits have from time to time been detected. For accounts of these beds we are indebted to MM. Cleve, Jentzsch, Laufer, Keilhack and Wahnschaffe.[1] Amongst the forms recorded by Keilhack are the following:—*Cervus elaphus*, *C. dama fossilis* (?), *C. Capreolus*, *Bos*, sp., and three species of fish—carp, perch, and pike. The land and fresh-water shells are *Pupa muscorum*, *Vertigo antivertigo*, *V. pygmæa*, *Helix pulchella*, *Achatina lubrica*, *Valvata macrostoma*, *V. piscinalis*, *Bithynia tentaculata*, *Limnæa minuta*, *L. auricularia*, *L. palustris*, *Planorbis marginata*, *P. lævis*, *Pisidium nitidum*, *P. pusillum*, *P. amnicum*, *Cyclas cornea*, *Unio*, sp. Plants are represented by oak (*Quercus robur*, *Q. sessiliflora*), beech, white birch, hornbeam, alder (*Alnus glutinosa*), species of willow and poplar, bog-myrtle, maple (*Acer campestre*, *A. platanoides*), lime-tree, whortle-berry, dogwood, bladderwort (*Utricularia Berendti*), Scots fir, and many diatoms. The vertebrates point to temperate climatic conditions—the mammals representing a forest fauna, while the fish are still natives of Middle Germany. Dr. Keilhack remarks, however, that the carp, although living there in old 'diluvial' times, subsequently disappeared, and was re-introduced from the south by the Romans. From the flora we may infer that the climate was somewhat more genial than that now experienced in North Germany. From fresh-water marls, &c., in the diluvial deposits of the same region (North-east Hanover) Dr. Laufer obtained numerous relics of plants and animals, amongst which are the following forms—hitherto unknown from this horizon in Western Germany:—*Rhinoceros*, sp., *Emys europæa*, (tortoise), *Abramis brama* (bream), *Helix austriaca*, and *Populus tremula*, *Corylus avellana*, *Ceratophyllum demersum*, *Juglans regia* (walnut), *Fraxinus excelsior* (common ash), *Arundo phragmites*, *Equisetum palustre*. It is interesting to note the occurrence of the walnut, for this tree is not now

[1] Cleve and Jentzsch, *Schrift. d. physik-ökonom. Ges. z. Königsberg*, Bd. [illegible]6; xxii.; Laufer, *Jahrb. d. königl. preuss. geolog. Landesanst. f.* 1881, p. 49[illegible]; *ib. f.* 1883, p. 310. Keilhack, *op. cit. f.* 1882, p. 133; Wahnschaffe, *op. cit.* [illegible]29. *f.* 1884, p. 436; *Vortrag gehalten im Bildungsverein zu Rathenow*, October 1885.

igenous to Europe, having been introduced into Greece l Italy some centuries before our era. The fresh-water beds cribed by Wahnschaffe as underlying the lower boulder-y near Rathenow, on the Havel, a tributary of the Elbe, ve yielded a number of shells, all of which, with the excep-n of *Paludina diluviana*, still live in the lakes and rivers North Germany. Thick layers of diatomaceous earth are o met with in the same position in that neighbourhoood.

From the position occupied by these interesting deposits y are described as 'preglacial.' There is nothing in the aracter of the fauna and flora adverse to that conclusion. the other hand there is an absence of any characteristic glacial species—the plants and animals forming just such assemblage as we might expect to meet with upon an erglacial horizon. All that we are justified in affirming th regard to the position of the deposits seems to me to be nply this, that they are older than the glacial accumulations ich overlie them. It is obviously impossible to assert that ey are older than the advent of the early Baltic glacier scribed by Nathorst and others; indeed many of the marl-ls described by Laufer appear to rest upon the sands of older or 'lower diluvium' and to be overlaid by the eschiebe Sand' of the 'upper diluvium,' which would seem indicate their interglacial age.

The next stage in the glacial succession is that known as erglacial. It is represented by terrestrial, fresh-water, and arine deposits, which are met with at intervals over a vast ea, from the shores of the North Sea as far east as Moscow. l these deposits are assigned by the majority of geologists the Continent to one horizon. They believe that there ve been only two glacial epochs, separated the one from e other by an interglacial epoch of more genial conditions. he 'lower diluvium' represents, in their view, the accumu-tions of the first cold epoch, while the 'upper diluvium' nbraces the glacial deposits of the second. Although I am mpelled to dissent from that opinion, I shall here describe he interglacial deposits under one section, just as if they all ertained to one and the same horizon. When I have com-pleted my review of the evidence it will be necessary to con-sider the question of the glacial succession as a whole.

The reader who has followed me so far may remember that the interglacial deposits of Britain were described as occurring for the most part in mere patches or sheets of more or less limited extent. It is the same on the Continent. Extensive regions may be traversed without meeting with a single trace of any interglacial deposit. Even in their absence, however, we frequently encounter evidence that seems suggestive of climatic changes. Upper and lower boulder-clays cover many wide regions almost continuously, and in clear exposures the one is often seen reposing on the denuded and disturbed surface of the other. Thus in the annexed section from Sweden two boulder-clays are shown—'the lower darker in colour and containing fewer big stones than the upper. Both, however,' says Törnebohm,[1] 'have evidently been formed in the same way, and are true *moraines de fond*. There is usually a sharp line of demarcation between them,

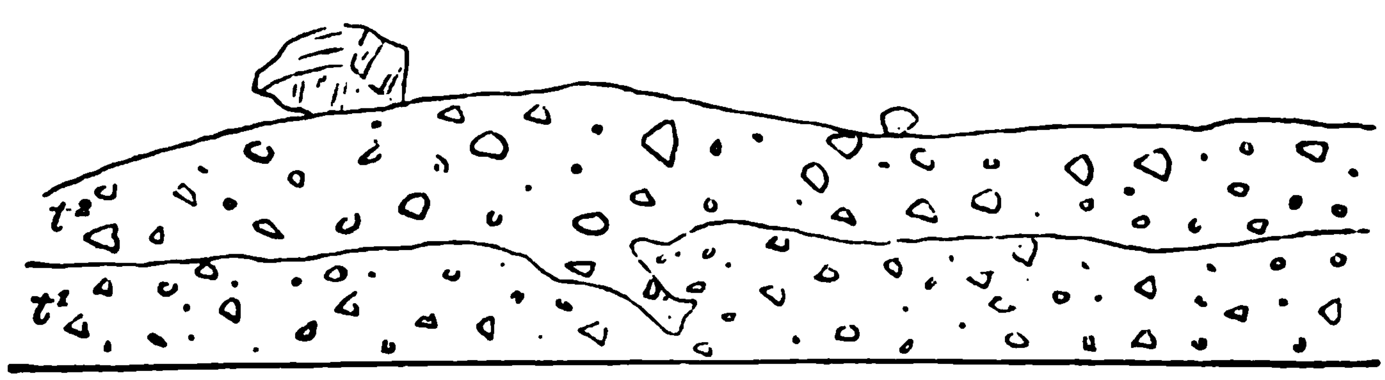

Fig. 74.—Upper and lower till in railway cutting in Wermland. (A. E. Törnebohm.)

and in some places the lower till has been partly broken up and denuded before the upper till was deposited.' The fact that the lower till exhibits such marked evidence of denudation underneath the upper and overlying mass 'seems to indicate,' Törnebohm remarks, 'that during the glacial period there was a great interval of comparatively mild climate, during which the ice retreated to the mountains; the land, however, was not at this time submerged. When the ice-sheet once more overspread the country it would obliterate any fresh-water deposits that might have been laid down in the interval.' Traces of glacial fresh-water beds, however, are not wanting—Dr. Nathorst having detected these many years ago in Scania. The beds referred to contain plants which,

[1] In a letter to the author. See J. Geikie, *On Changes of Climate during the Glacial Epoch*, p. 24.

according to Nathorst, indicate a climate as severe as that of Northern Norway. The same geologist has given the following table as embodying the results of his investigations into the glacial and interglacial deposits of Sweden and Denmark:—

POST-GLACIAL FORMATIONS	*Peat* with	Quercus sessiliflora, Q. robur. Pinus sylvestris. Populus tremula, Betula nana.
	Clay with	Betula nana, Salix herbacea, S. reticulata, Dryas octopetala, Cytheridea torosa, Limnea limosa, Pisidium, Anodonta, Salix polaris.
GLACIAL PERIOD		*Glacial Deposits. Boulder-clay.*
INTERGLACIAL	*Clay* with	Salix polaris, Dryas octopetala, Limnea limosa, Pisidium, Anodonta, Cytheridea torosa.
GLACIAL PERIOD		*Glacial Deposits. Boulder clay.*[1]

Herr Holmström has also described similar deposits as occurring at Klågerup, in Scania, in the following descending series:—

Yellow till with scratched stones.
Brown sand and yellow glacial fresh-water clay.
Grey marly sand.
Blue glacial fresh-water clay.
Blue till with scratched stones.

The fresh-water clays have yielded—1st. (Shells) *Pisidium pulchellum* (Jen.); *P. obtusum* (Pfeiff); *P. Henslowianum* (Jen.); *Anodonta anatina; Limnæa lagotis* (Schr.); 2nd. (Plants) *Dryas octopetala*, *Betula nana*. From these facts Holmström considered that he had evidence of an interglacial epoch. The lower blue till is very thick, and extends almost continuously over the whole country. It points to the former existence of an extensive *mer de glace* which covered the whole land, destroying all life. The shells and plants found in the fresh-water clays must therefore, according to Holmström, have come in from the south when the ice retired. Then, at a later period, some local glaciers crept down from the great mass of ice that still lingered in the North, covering with morainic matter the fresh-water clays which, during the interval, had accumulated in pools and lakes upon the surface of the older till.[2] MM. E. Erdmann and Fegræus have also described the occurrence of fresh-water interglacial beds between the boulder-clays of Scania.[3]

[1] *Kongl. Vetenskaps-Akademiens Förhandlingar*, 1873, No. 6.
[2] *K. Vet.-Akad. Förh.* 1873, No. 1.
[3] Erdmann, *Geol. För. i Stockholm Förh.* Bd. ii. p. 13; Fegræus, *ibid.* Bd. xii. p. 49.

More recently Dr. A. G. Högbom has given some account of similar interglacial deposits which are seen near Östersund in one of the islets of Storsjön, Jemtland. The surfaces of the laminated clays show worm-tracks, and the beds have yielded plant remains, amongst which are several mosses, determined by Dr. W. Arnell. They are all species which range throughout Scandinavia, and therefore yield little information as to the character of the climate during the deposition of the beds.[1] These interglacial accumulations appear to have a considerable development in Sweden, and indicate the former existence of large lakes. Certain other deposits occur in South-west Scania, occupying an interglacial position, but it is doubtful whether they are of marine or supramarine origin, the only fossil they have yielded being the remains of a high northern species of cod (*Gadus polaris*, Sab.).

The late Dr. Karl Pettersen also met with evidence of interglacial conditions in Northern Norway. Following the older glacial epoch of that region came a period of partial submergence, when the sea-level stood some sixty-three metres higher than at present—conditions which are suggested by the appearance of sands and clays containing an arctic-marine fauna. The sea-level then gradually sank till it reached thirty-eight to thirty-five metres above the present coast-line, when the glaciers again reached the sea and erratics were floated along the coast. This stage is marked by conspicuous rock-terraces (*Strandlinier*), and by gravel, sandy clay, and stony sand.[2]

In Schleswig and the Danish islands (Seeland, Fyen, Langeland, Ärö) shell-beds are found intercalated between two separate boulder-clays.[3] These interglacial beds, when well developed, consist of a lower clay characterised by the presence of *Cyprina islandica*, and an upper clay, the characteristic form of which is *Mytilus edulis*. Occasionally sandy layers, containing fresh-water shells, are interbedded with the *Mytilus*-clay, and more rarely with the *Cyprina*-clay. Of the eighteen species of molluscs obtained from these beds,

[1] *Geol. För. i Stockholm Förh.* Bd. xv. p. 28.
[2] *Tromsoe Museums Aarshefter*, ix. p. 67.
[3] Johnstrup, *Indbydelsesskrift til Kjöbenhavns Universitets Fest*, &c. 1882, p. 46.

o fewer than eleven, according to Munthe, have a southern ange, four are widely distributed forms, and only three have northern range. All are still living in the Kattegat—the nly exceptions being *Tapes aureus* and *T. pullastra*—the ormer occurring in the Skagerack and the latter in Limfjord. 'he same deposits have yielded *Balanus balanoides, Echinoyamus pusillus, Echinocardium cordatum,* many diatoms, few rhizopods (*Nonionina depressula, Rotalina Beccarii, 'olymorphina angusta*), and an ostracod (*Cytheridea papilsa*).[1]

In Eastern Holstein similar interglacial beds have been etected, as at Fahrenkrog and Tarbeck, between Kiel and [amburg. These beds have yielded the following :—*Ostrea lulis, Mytilus edulis, Cardium edule, Littorina littorea, Hyrobia ulvæ,* Aporrhais pes pelicani, Cardium minimum,* 'actra subtruncata, Scrobicularia piperata,* Tellina balthica, 'ya arenaria* (?), *Saxicava arctica,* Utriculus umbilicatus,* alanus,* sp., *Cythere lutea,* Rotalina Beccarii.* Those ıdicated by an asterisk have not yet been obtained in the *yprina*-clay of Denmark, but all (with the exception of *'triculus umbilicatus*, a Kattegat form) are found living in ıe Western Baltic or in the Sound.

Interglacial marine and fresh-water deposits likewise ppear in the islands of Rügen and Bornholm.[2] But the terglacial accumulations of the Baltic area attain their best evelopment in West and East Prussia.[3] They frequently each a considerable thickness, and extend continuously for ome distance between underlying and overlying glacial ccumulations. Sheets of clay and sand predominate, but yers of gravel now and again occur, and here and there beds

[1] Dr. Munthe, *Bihang til K. Svenska Vet.-Akad. Handl.* Bd. xviii. Afd. ii. o. 1.

[2] Munthe, *op. cit.* pp. 58, 69. H. J. Haas describes interglacial peat as ccurring at the south-eastern corner of Kiel Bay, but the plants have not yet een determined (*Die geolog. Bodenbeschaffenheit Schleswig-Holsteins*, p. 63).

[3] They have been carefully studied by Dr. Jentzsch. See especially *Jahrb. d. königl. preuss. geol. Landesanstalt für* 1884, p. 438, and *Schrift. d. Naturforsch. Ges. zu Danzig*, N. F. Bd. vii. Hft. 2. See also Schirmacher, *Inaugural Dissertation, Königsberg*, 1882; Schröder, *Jahrb. d. k. preuss. geol. Landesanst. für* 1885, p. 219; 1887, p. 349. Dr. F. E. Geinitz has recently recorded the first occurrence of interglacial beds in Mecklenburg (at Schwann, south of Rostock) which have yielded a North Sea fauna. *Archiv d. Ver. d. Fr. d. Naturgesch. in Mecklenburg*, 1893, p. 135.

of diatomaceous earth [1] and peat are met with. Some of these deposits are of marine origin, others are fresh-water or terrestrial. They have yielded the following :—

MARINE MOLLUSCS :—*Ostrea edulis, Mytilus edulis, Cardium edule, C. echinatum, Cyprina islandica, Tapes edulis, Mactra subtruncata, Scrobicularia piperata, Littorina littorea, Scalaria communis, Cerithium reticulatum, Nassa reticulata, Tellina balthica, Corbula gibba.*

FRESH-WATER MOLLUSCS :—*Anodonta anatina, Unio pictorum, Lymnæa auricularia, L. ovata, L. stagnalis, Pisidium obtusale, Bithynia tentaculata, Valvata piscinalis, V. macrostoma, Planorbis carinatus.* In the same beds with these occur Ostracods, Diatoms, and Equisetum.

LAND MAMMALS :—*Elephas primigenius, Bos primigenius, Cervus megaceros, Equus caballus, Rhinoceros tichorhinus.*

The general facies of the molluscan fauna is temperate—all the species being North Sea forms, and (with the exception of *Tapes edulis*) still living in the Kattegat. Most of them, indeed, occur likewise in the Western Baltic, from the Sound to the Little Belt—*Ostrea edulis, Cardium echinatum,* and *Scalaria communis* being the only exceptions. The highest level at which marine interglacial beds have been met with in West Prussia is at Neudeck near Freistadt, some 52 miles south from the Baltic. Here Jentzsch found thick sandy deposits crowded with *Cardium edule, Tellina balthica,* and *Cyprina islandica,* at a height of 114 metres (374 ft.) above the sea.[2] Nowhere else within the Baltic area do interglacial beds attain this level. In Bornholm their greatest elevation is about 50 ft. only; in Rügen they occur at a height of 130 to 160 ft., in Holstein at 260 ft., in the Danish islands of the Western Baltic at 30 ft. or thereabout, while in Scania they occur at and below the sea-level. It may be noted that Jentzsch and his confrères always carefully distinguish between derivative fossils and fossils which occur in their original bedding-place. Thus the lower and upper diluvial accumulations not infrequently contain fossils, but all these are recognised as derivative : those in the 'lower boulder-

[1] Diatomaceous earth of fresh-water origin was recognised a number of years ago, intercalated between two boulder-clays, in Mecklenburg. See F. E. Geinitz, *Beitrag zur Geologie Mecklenburgs*, 1880, p. 40.

[2] *Zeitschr. d. deutsch. geolog. Ges.* Bd. xlii. p. 597.

lay ' and its associated aqueous deposits having been derived rom the ' early glacial beds ' described on p. 442, while those btained in the upper diluvium have obviously come from iterglacial beds.

Without attempting to trace the probable shore-line of ie sea in which those shell-beds were deposited, we may et conclude that the Baltic, during interglacial times, had pen communication with the North Sea across Holstein, onsiderable portions of Schleswig and the Danish islands eing contemporaneously submerged. The Western Baltic eems indeed to have opened freely into the Kattegat.[1] The cies of the marine fauna and diatomaceous flora suggest mperate conditions, for the assemblage of forms is similar that now occupying the North Sea and the Kattegat.

The character of the fresh-water shells and land-mammals om the deposits of West and East Prussia is in keeping ith that of the marine life. But from the association of arine and fresh-water beds, and from the occurrence of both different levels throughout the Baltic coast-lands, it is ovious that the physical changes have been somewhat comlex. If all these interglacial deposits belong to one stage, ey show us that the submergence which they indicate was ot suddenly effected. We seem to have in the deposits the ecords of a considerable period of time, during which changes f the sea-level took place gradually and the climate varied. For one can hardly believe that the fresh-water interglacial eds of South Sweden, with their arctic plants, are quite synchronous with the interglacial beds of Denmark and East Prussia.

[1] The North Sea fauna has been traced south to the Elbe, where at Blankenese and Stade (below Altona) marine deposits of interglacial age have been detected. See *Jahrb. d. königl. preuss. geolog. Landesanst. f.* 1884, p. 497, for references to authorities.

CHAPTER XXX.

GLACIAL PHENOMENA OF NORTHERN EUROPE—*continued.*

Interglacial deposits of Grünenthal (Holstein); of Fahrenkrog; of Lauenburg, on the Elbe; of Kottbus in Brandenburg; of Rixdorf, near Berlin; of Troizkoje, Moscow—The 'upper diluvium'—Moraines of the Baltic Ridge—Southern limits of the 'upper boulder-clay' of North Germany, &c.; this boulder-clay on same horizon as the 'upper boulder-clay' of Britain—Moraines of Baltic Ridge the equivalents of district-moraines of British mountain areas—Four boulder-clays in Baltic coast-lands—Two boulder-clays in Elbe valley, &c.—One boulder-clay in Saxony—Summary.

IN the preceding chapter some account has been given of the interglacial deposits of the Baltic coast-lands. All the beds referred to appear to belong to one and the same stage of the Glacial Period: they are underlaid by the 'lower diluvium' and overlaid by the 'upper diluvium' of those regions. I have already expressed a doubt as to whether the boulder-clays in question can be correlated with those which are known under the same names in the countries lying to the south and south-east of the Baltic. But for the reasons already given I shall in the present chapter continue my account of the interglacial deposits before attempting to correlate the evidence.

Dr. Weber has recently described[1] the occurrence in the neighbourhood of Grünenthal, in Western Holstein, of certain peat-beds and associated fresh-water deposits which from many points of view are of great interest. They rest upon and are covered by glacial deposits, and are much folded and disturbed—appearances due to the pressure of the ice-sheet underneath which the overlying boulder-clay was accumulated. From the fresh-water clays have been obtained *Anodonta cygnea*, *Pisidium fontinale*, *Bithynia tentacula*

[1] *Neues Jahrb. f. Min. Geol. u. Pal.* 1891, vol. ii. pp. 62, 228; 1892, vol. i. p. 114; 1893, vol. i. p. 94.

mnæus stagnalis, L. auricularius, Valvata depressa, V. cris-a, Planorbis complanatus, P. spirorbis, Ancylus lacustris, ındant ostracod shells (*Cypris* ?), perch, carp, and elytra of ›tles (*Feronia cuprea, Drypta emarginata,* &c.). Amongst numerous plants of the peat-beds are pines and firs (no ger indigenous to Schleswig-Holstein), aspen, willow, ite birch, hazel, hornbeam, oak, lime, maple, cherry-tree, l juniper. Associated with these are *Ilex* and *Trapa* '*ans*, the presence of which, as Dr. Weber remarks, okens a climate like that of Western Middle Germany. other noteworthy form is an extinct water-lily (*Cratopleura satica*), closely related to one which appears in the inter-cial beds of Switzerland, and certain curious sausage- or ster-shaped fruits (*Paradoxocarpus*), which occur also in Cromer Forest-bed, and at Klinge, in Brandenburg, as ll be noted in the sequel. In one of the localities men-ned by Weber the interglacial peat yielded at its lowest 'el remains of Irish deer and a small horse, as also a ver-›ra of some very large fish. Towards the top of the same at occurred the following:—*Betula nana* (very abundant), *lix* (*repens* or *myrtilloides*), *S. Laponum* ?, *Vaccinium, tis Idæa, V. Myrtillus, Pinus sylvestris, Polytrichum* '*ictum*, &c. Dr. Weber remarks that in all the sections of at examined by him *Pinus sylvestris* is the most common e in the lowest and the uppermost layers, while the central rtions are characterised especially by *Cratopleura, Para-xocarpus, Tilia platyphylla, Prunus avium, Ilex aqui-ium*, and *Picea excelsa.*

More recently still the same observer has described the currence of interglacial peat at Fahrenkrog, about two les west of Segeberg, in East Holstein. A series of rings at this place passed through the following succession beds :—

Yellow boulder-clay	about 6 metres.
Peat	2-3 ,,
Blue clay, very hard, with fragments of flint scattered through it	3 ,,
Sand	10 ,,
Peat	0·7-0·9 ,,
Sand	22 ,,
Peat, not yet bored through.	

Dr. Weber has hitherto examined only the uppermost of the three peat-beds, which is exposed in section, showing a thickness of five feet. At this place it rests upon a bed of fine quartz sand, largely impregnated with organic matter, and rather more than a yard in thickness. In the lower part of this bed Dr. Weber obtained pollen of Scots fir, an oak (*Quercus pedunculata*?), and fragments of wood, some of which were oak and others apparently birch, while yet others could not be determined with certainty. Underneath this dark sand a bed of hard unstratified blue clay made its appearance. Scattered through it were small fragments of flint, and the clay did not effervesce with acids. It contained not the least trace of organic matter, and had all the appearance of a glacial accumulation. The peat-bed was overlaid by boulder-clay of the usual character. The section of the peat itself is given as follows:—

5. Wood-peat	0·75 metres.
4. Sphagnum-peat	0·30 ,,
3. Hypnum-peat	0·05–0·12 ,,
2. Compact (liver-like) peat	0·25 ,,
1. Dark grey sandy bed, with abundant plant-remains.	

The lowest layer (1) contains in abundance water-loving plants (*Ceratophyllum*, *Potamogeton*), oak, willow, and Scots fir—the conditions implied being water surrounded by those trees, of which the Scots fir was by far the most abundant. The compact peat with its pond-weeds, &c., brings before our eyes quiet water of moderate depth. In the adjacent forest the dominant tree was now the oak (*Quercus sessiliflora*)—the pine, so very common at first, being sparingly represented. Towards the close of the formation of layer 2, the fir (*Picea excelsa*) made its appearance. Amongst the many species met with in the compact peat are water-lilies (*Nymphæa*, *Nuphar*, *Cratopleura*), lime-tree, common maple, manna-ash, birch, alder, hazel, *Paradoxocarpus carinatus*, &c. The flora at the time of the formation of the hypnum-peat (3) was the same as that which flourished during the formation of the upper portion of the preceding compact peat (2)—only that the Scots fir had become still scarcer. The open water had now disappeared, and in its

e was a marshy bog—the surface of which appears to e been diversified here and there with clumps of bul-ies, and thickets of willow and birch, while in little pools omed the white lake-rose. The only remains of trees ch occur in this layer were probably blown into the sh from some adjacent forest. The sphagnum-peat ds much the same assemblage of plants as layer 3. oak, however, has now almost completely supplanted pine, while the fir (*Picea excelsa*) has become more mon, and the wet boggy marsh has dried up. Forest-s next overspread the place, forming by their remains wood-peat (5). At first the wood consisted principally oaks, commingled with which were a few firs and still er pines—the underscrub being composed chiefly of els and occasional birches. Next the beech appears, and first grows side by side with the oak, but the latter dually becomes less common, while at the same time the el and the birch likewise diminish. In the upper part of peat not a trace of the oak occurs; the fir, however, tinued to flourish in the beechen forest, while the pine ppeared. Here the tale told by the peat abruptly ends; it is probable, Dr. Weber remarks, that the pine once re became as plentiful as it had been during the forma-n of the lower layers. This, at all events, was the case, we have seen, in the interglacial peat of Grünenthal and er places in West Holstein. According to Dr. Weber the ındant development of the pine in the lower layers of the t indicates a more continental climate than now obtains Holstein. Later on the climate became more oceanic, d induced the immigration of the stone oak (*Quercus sessili-ra*), and its associates—the hazels, limes, maples, alders, &c. is change of climate would not of itself have been inimical the pine, but that tree could not flourish in the dark shade the oak and its associates. The subsequent decline and appearance of the oak, in like manner, cannot have been e to climatic changes, for the same oceanic conditions ntinued while the uppermost layers of the peat were being med. It is much more probable that it simply with-ew from the dark shade of the beech and fir. But the appearance of the pine towards the close of the period

represented by the interglacial peat shows that the climate was again assuming a more continental character.[1]

A few years ago Dr. Keilhack described an interesting section of what he considered to be interglacial beds at Lauenburg on the Elbe (about 52 miles above Hamburg).[2] The lowest beds seen at that place are sands containing abundant sea-shells, chiefly the common cockle, some of the specimens having the valves united. Along with the cockle the common mussel and *Tellina balthica* also occur. Above these sands, which are somewhat disturbed, comes a sheet of 'lower boulder-clay, and overlying that appears a bed of peat with partings of bituminous sand. The peat varies in thickness from 9 to 13 ft., and can be seen in section for a distance of 360 ft. It is overlaid by sand and gravel, which, according to Keilhack, are the fluvio-glacial deposits usually associated with the 'upper boulder-clay.' He thought he had also found evidence in one place of an overlying 'upper boulder-clay:' but in this, as MM. H. Credner, F. E. Geinitz, and F. Wahnschaffe pointed out, he was mistaken.[3] Dr. Keilhack, after revisiting the section, maintains his original contention that the peat is of interglacial origin—since it is overlaid by fluvio-glacial accumulations. It may be added that the flora of the peat has been studied by Dr. von Fischer-Benzon, who likewise assigns the bed to an interglacial horizon. Dr. Schröder, who accompanied Dr. Keilhack on his last visit to Lauenburg, also agrees with the latter in his interpretation of the evidence.[4] More recently MM. Credner, Geinitz, and Wahnschaffe have reiterated their opinion that the sands which overlie the peat are not of 'diluvial' but postglacial origin. They maintain, in short, that these deposits are *remaniés*, and that the peat, therefore, cannot be of interglacial age.[5] They emphasise the fact that all the plant-remains obtained from the peat are still natives of West Germany, and that the bed cannot, therefore, be so old as Keilhack has maintained. It does not appear, however, that the peat has been

[1] 'Ueber die diluviale Flora von Fahrenkrog in Holstein,' *Engler's bot. Jahrb.* Bd. xviii. 1893, Beiblatt, Nr. 43.
[2] *Jahrb. d. königl. preuss. geolog. Landesanst. f.* 1884, p. 211.
[3] *Neues Jahrb. für Min. Geol. u. Pal.* 1889, Bd. ii. p. 194.
[4] *Ibid.* 1892, Bd. i. p. 151.
[5] *Ibid.* 1893, Bd. i. p. 33.

bjected to the same close examination as those described Dr. Weber, while the fact that the overlying sands and avels are *remaniés* cannot be considered as a decisive gument against the interglacial age of the bed. Dr. R. von scher-Benzon, who is so intimately acquainted with the at-deposits of Schleswig-Holstein, does not doubt its intercial age. In the regions studied by him many of the peatds can be shown by their position alone to be interglacial, : they rest upon and are covered by boulder-clay or by ads and gravels of glacial age. Others again, although not vered by glacial deposits, yet yield the same flora as those at are intercalated between glacial accumulations.[1] While me doubt must attach to Keilhack's determination of the e of the Lauenburg peat, its true postglacial age can hardly said to have been satisfactorily established. A more ex-ustive investigation, botanical and geological, than it has t received seems desirable.[2]

Another peat-bed which has yielded a most abundant ra is that of Klinge, near Kottbus in South-east Branden-rg. For our knowledge of the plants we are indebted to ofessor Nehring and his collaborateurs Dr. Weber, Pro-sor Wittmack, and Herr Warnstorf.[3] The flora, according Professor Nehring, has close affinities to that of the Cromer rest-bed ; on the other hand, it would seem to have the me general facies as the interglacial flora of Beldorf and oss-Bornholt in Holstein. Some forty species of plants ve been determined, among which the most noteworthy an extinct water-lily (*Cratopleura helvetica f. Nehringi*), sely allied to, if not identical with, a form which occurs the interglacial deposits of Switzerland. The remains of is lily are very abundant at Klinge. Common also are curious 'sausage-shaped' fruits and certain small seeds

[1] *Abhandl. des naturwiss. Ver. Hamburg*, 1891, Bd. xi.

[2] If it were true that all interglacial peat is characterised by the presence ome extinct or no longer indigenous plants, the occurrence of none of these Lauenburg would be, so far, evidence of its postglacial or recent age. But s not the case that extinct or non-indigenous forms are always present in t of interglacial age. The Lauenburg peat, however, may possibly belong a later interglacial stage than the beds described by Dr. Weber and Professor hring. See *postea*.

[3] See Nehring's communications in the *Naturwissenschaftliche Wochen-rift*, Bd. vii. (1892), Nos. 4, 24, 25, 45 ; *Ausland*, 1892, No. 20 ; *Botanisches ntralblatt*, 1892, No. 30.

having a metallic lustre—both belonging to some hitherto undetermined species.[1] Among the trees the following are represented :—*Pinus sylvestris*, *Picea excelsa*, *Betula verrucosa*, *B. odorata*, *Alnus*, sp., *Salix aurita*, *S. repens*, *S. caprea* ?, *S. cinerea* ?, *Populus tremula* ?, *Corylus avellana*, *Carpinus betulus*, *Quercus*, sp., *Tilia platyphylla* ?, *Acer campestre*, *Ilex aquifolium*. Various mosses, marsh-plants, &c., have also been determined. The facies of this flora, as Dr. Weber remarks, implies a well-marked insular climate—the occurrence of holly in the heart of the Continent, where it no longer grows wild, being particularly noteworthy. It is now restricted in Germany to the north-west and west, from Rügen to the Black Forest.

The peat of Klinge forms a bed six and a half feet thick, intercalated between an upper and a lower bed of plastic clay —the series being underlaid by gravel and overlaid by sand which rests discordantly upon the upper clay. The following is the succession as given in detail by Professor Nehring :—

Sand	Humous sand, about ½ metre.
	Bedded sand, with rounded stones and boulders in places, 2 metres.
Clay	Peaty clay, with obscure plant-remains, about 1 metre.
	Plastic clay, pure, generally without stones, 2 metres.
	Clay, with peaty layers, ½ metre.
Peat	= Peat, with abundant well-preserved plants, 2 metres.
Clay	Hard ferruginous clay, about ½ metre.
	Plastic clay, generally stoneless, 4 metres.
Gravel	= Arenaceous gravel of unknown thickness.

Professor Credner has shown that the gravel which forms the base of the series contains many flints and other materials of northern origin, and a large number of stones which have been carried north from the Sudetic mountains.[2] The deposit is therefore of 'diluvial' age—the materials of which it is composed have been derived in large part from glacial

[1] The sausage-shaped fruits are small (8–9 mm. in length, 2–2¼ mm. in diameter) and have puzzled botanists. Nehring believes they are probably water-plants, and has named them *Paradoxocarpus carinatus*. Dr. H. Potonié thinks they are allied to *Folliculites Kalten-nordheimiensis* from the Tertiary of Kalten-Nordheim near Meiningen. *Folliculites carinatus*, as he proposes to term the interglacial form, he believes to be a drupe or stone-fruit. (*Sitzungs-Berichte d. Ges. naturforsch. Freunde*, 1892, p. 199.) Mr. Clement Reid has obtained the same fruits in the Cromer Forest-bed, and in lacustrine beds overlying the chalky boulder-clay in Suffolk. (*Trans. Norfolk and Norwich Nat. Soc.* vol. v. p. 382.) He thinks they are probably the fruit of one of the Niadeæ, and with him Dr. Weber (who has obtained *Paradoxocarpus* from the interglacial peat of Holstein) agrees.

[2] *Ber. d. königl. Sächs. Ges. d. Wissensch.* Oct. 1892.

leposits. Before the peat began to form, a glacial epoch had ome and gone, and hence the flora of Klinge is not of pre-lacial age. Nehring points out that the various species of lants are not scattered promiscuously through the deposits. n the contrary, many are confined to definite horizons, so aat a certain succession can be traced—one set of plants iving place, as it were, to another when the section is ollowed from below upwards. He pictures the formation of e peat as having commenced in a pool or lakelet occupy-g a hollow in the surface of the lower clay, and perhaps ommunicating with other waters. In this lakelet flourished any water-plants, such as *Ceratophyllum submersum* and *. demersum, Najas marina, Nuphar luteum, Nymphæa.* he banks were clothed with a mixed forest vegetation, onsisting chiefly of hornbeam, birch, and fir, amongst hich appeared sporadically pine, maple, lime, hazel, oak, olly, and willows. Later on, the above-mentioned water-lants, together with the now extinct *Cratopleura*, began to ve place to mosses (*Hypnum fluitans*, and *H. aduncum*) by hich they were by-and-by superseded—a change which ould seem to indicate a gradual lowering of temperature. nd this inference is further strengthened by the appearance the dwarf birch (*Betula nana*), detected by Professor athorst in the upper clay. In connection with this it is im-rtant further to note that in the upper part of the peat ehring has found no trace of lime, maple, hazel, oak, or lly. These species, he remarks, which betoken a mild mate, seem to have disappeared from the neighbourhood Klinge before the formation of the peat-bed was completed, ile birches, firs, and willows reigned in their stead.

Professor Credner has suggested that the plant-remains the peat may have been drifted into their present position fluviatile action. He is of opinion, indeed, that the hole series of deposits has been formed in this way, while e overlying sand, he thinks, is a deposit rearranged by the tion of the wind, &c. But Dr. Nehring points out that e very perfect condition in which the plant-remains occur egatives the supposition that they have been carried for ny distance.[1] The fruits and seeds are quite intact, many

[1] *Sitz.-Ber. d. Ges. naturf. Freunde*, 1892, p. 158.

of the most delicate leaves being wholly uninjured. Nehring also mentions the fact that the tree-stems which occasionally occur are usually upright or nearly upright in the peat, and in one place a group of stems was seen in such a position as to suggest that the trees had been overthrown *in situ* by wind.[1] Many of the branches occurring in the peat have been gnawed and barked, most probably by beavers—which only feed on freshly-fallen trees, and teeth of the beaver, it may be added, have quite recently been found in the same deposit. Dr. Nehring concludes that not only have the water-plants of the peat grown *in situ*, but the trees also have flourished in the immediate neighbourhood. Besides beaver, the Klinge deposits have yielded remains of elk, rhinoceros (sp.), a small fox (?), horse, and Megaceros. This last is not the typical Irish deer, but a variety (*C. megaceros*, var. *Rufii*, Nehring).

The sand overlying the peat and clay is described by Dr. Keilhack as northern 'Geschiebesand.' The same view as to its character is held by Professor Wahnschaffe, who, after a careful examination of the deposits, confidently concludes that the peat-bed of Klinge has been formed in the manner suggested by Professor Nehring, and is clearly of interglacial age.[2] More recently still, Dr. Weber has subjected each of the beds to a close botanical analysis, with the result that he is compelled to dissent from Professor Credner's view, and to support the general conclusions arrived at by Professor Nehring. During the formation of the Klinge peat an insular climate with a west European flora prevailed far into the heart of the Continent.[3]

The fossiliferous deposits of Lauenburg occur within the peripheral area over which the 'upper diluvium' of Western and Middle Germany is distributed, while the interglacial beds of Klinge appear to lie either on the southern limits reached by the 'upper boulder-clay' or a little beyond. Some sixty miles to the north-west, and therefore well

[1] It should be mentioned that the clays amongst which the peat is interbedded have been worked for many years, and that the facts relating to the mode of occurrence of the stems have been observed for a long time by the owners of the tileries.

[2] *Sitz.-Ber. d. Ges. naturf. Freunde*, 1892, p. 193

[3] *Engler's botanische Jahrbücher*, Bd. xvii. (1893) Hefte 1 and 2.

within the region covered by the boulder-clay in question, fresh-water interglacial deposits are well developed. These consist of sands and gravel, overlying the lower boulder-clay, and covered by the upper boulder-clay of that region, and are exposed in numerous openings at Rixdorf and other places in the neighbourhood of Berlin. The mammalian remains obtained there embrace the following:—mammoth, *Elephas antiquus*, tichorhine rhinoceros, leptorhine rhinoceros, horse, musk-ox, urus, bison, caribou, elk, Irish deer, stag, wolf, and a species of bear. It is hardly possible that all these animals lived side by side. There is a mingling of northern, temperate, and southern species. The beds of Kreuzberg, Rixdorf, Britz, and Tempelhof, near Berlin, and those that occur in the neighbourhood of Königs-Wusterhausen, Cöpenick, and Ketzin, probably represent a long interglacial epoch, during which the climate gradually changed from cold to genial, and from genial to cold. *Elephas antiquus* and *Rhinoceros leptorhinus* are southern species which probably reached the region in question when temperate conditions prevailed.[1]

As large areas of the drift-covered regions of Northern Europe have not yet been examined carefully, we may anticipate the discovery of many other interglacial finds similar to those which have rewarded the investigations of German geologists. It is probable, for example, that the old lacustrine formations, with remains of mammoth and rhinoceros, which are widely distributed in Central Russia, represent the interglacial deposits of Germany just described. The formations in question overlie the glacial accumulations of the lower diluvium, which is the only glacial division met with in that region. Besides the mammalian remains referred to, the lacustrine deposits have yielded the trunks and leaves of oak, pine, birch, &c., although the surrounding region shows no forest vegetation now, but presents much the character of a steppe.[2] Among the more interesting examples of these fresh-water formations are those which occur at Troizkoje in the neighbourhood of Moscow. They

[1] See G. Berendt and W. Dames, *Geognostische Beschreibung der Umgegend von Berlin*, 1885, and the authorities cited therein.

[2] S. Nikitin, 'Sur la constitution des dépôts quaternaires en Russie,' &c., *Congrès Intern. Archéolog.* Moscow, 1892.

consist of loam and sand with layers of peat, and have yielded remains of the following:—oak (*Quercus pedunculata*), alder (*Alnus glutinosa*, *A. incana*), white birch, common hazel, maple (*Acer platanoides*), Scots fir, willow, water-lilies (*Nuphar*, *Nymphæa*), mammoth, pike, perch, *Anodonta*, wing-cases of beetles, and diatoms. The character of the flora shows that the climate of Central Russia was formerly milder and more humid than it is now. M. Krischtafowitsch points out that the beds rest upon glacial deposits, and are covered by sand and gravel with northern erratics, and he is of opinion, therefore, that they are of interglacial age.[1] The overlying sand and gravel, however, are in all probability *remaniés*, and derived from the denudation of 'lower diluvium.' As we shall see presently, there is no reason to believe that Central Russia was invaded by more than one ice-sheet—that of the epoch of maximum glaciation. But as the fossiliferous deposits are certainly not preglacial, and as they cannot be postglacial, they must be assigned to an interglacial horizon. Many similar deposits, as I have indicated, occur in Central Russia, and it is to be hoped that they will erelong be carefully studied. They include diatomaceous marls, calcareous tufa, peat, lignite, and clays, &c., with fresh-water shells and plant-remains. All the evidence goes to show that after the great ice-sheet had vanished, Central Russia was sprinkled plentifully with lakes large and small, and experienced a less extreme climate than now. Thereafter followed an epoch of erosion, when the lakes were drained and their deposits eroded by streams and rivers. Krischtafowitsch points out that analogous facts are met with in Northern Russia. Formerly the waters of the lakes Ladoga, Onega, and Ilmen attained a considerably higher level than at present. Ladoga, for example, was some fifty feet deeper than now. At a later period, however, its surface fell to twenty feet below its present level, at which time its banks were clothed with forests of oak.[2]

In Central Russia only one boulder-clay is known, but in Lithuania and Poland both upper and lower diluvium make

[1] *Bull. de la Soc. Impér. des Naturalistes de Moscou*, No. 4, 1890.

[2] Krischtafowitsch, *Trudui S. Petersb. Obschestva Otd. Geol. i Min.*, t. xx. part 2.

their appearance—the two boulder-clays being usually separated by thick accumulations of sand and stratified clay, &c. These deposits appear to be unfossiliferous, and it is possible, therefore, that they may be largely fluvio-glacial in origin. Dr. Siemiradski, however, describes the occurrence in Southern Poland of löss with land-shells, which occupies an interglacial position.[1]

Having now passed in review the deposits included by continental geologists in their 'lower diluvium,' we come next to the 'upper diluvium,' consisting, like the lower, of boulder-clay with underlying and overlying erratic gravel and sand. These deposits are believed to be the morainic and torrential accumulations of another general *mer de glace* which invaded the low grounds of Northern Germany, &c. It is well known and admitted on all hands that this later ice-sheet did not overflow nearly so wide an area as that of the lower diluvium. There is usually a well-marked distinction between the boulder-clays of the lower and upper diluvium. The former are generally tougher and more abundantly crowded with stones and boulders—the colour of the clay being often dark-grey or greyish-blue. Moreover, the included erratics have travelled in directions which do not correspond to those followed by the stones and blocks in the upper boulder-clay. The general trend of the erratics in the lower boulder-clay is indicated by the thin red lines on the map (Plate IX.)—a trend that corresponds with the direction of glacial striæ, *roches moutonnées*, and the folding of disturbed rock-surfaces under the clay. The boulder-clay of the upper diluvium is now and again yellowish or even reddish in colour,[2] and the direction of transport of its materials proves it to be the ground-moraine of an ice-sheet, the general trend of which was influenced by the Baltic depression. It is very important that the southern limits reached by that ice-flow should be ascertained. According

[1] *Jahrb. d. k. k. geol. Reichsanstalt*, 1887, Bd. xxxix. p. 451.

[2] The colour of the boulder-clay is not a character on which one can always depend as a means of differentiation. The reddish or yellowish tint is frequently the result of oxidation—it is, in short, often only the weathered surface of the clay that shows this colour, the lower grey or bluish till is not infrequently tinted superficially in the same way. When the upper clay is thick its lower portions may be as dark and dingy in colour as any mass of normal lower boulder-clay.

to Dr. Klockmann,[1] the river Elbe forms its approximate boundary in Western Germany. Dr. Wahnschaffe, on the other hand, records its occurrence in the neighbourhood of Magdeburg.[2] It would appear to be somewhat inconstant in that district, sometimes presenting the aspect of normal boulder-clay, at other times being represented by a bed of erratics which occurs immediately underneath the overlying löss.

The same geologist further maintains that the gravel and sand of the Luneburg Heath (Hanover), a moory region lying between the Elbe and the Aller, are also on the same geological horizon.[3] These accumulations, forming broad sheets, banks, and mounds of sand, &c., with erratics, cover a wide area in Hanover and extend south-east into Altmark. From the descriptions given by Wahnschaffe, Girard, Laufer, and others, one cannot help suspecting that in these deposits we see the morainic and fluvio-glacial accumulations that mark the limits reached by the *mer de glace* of the upper boulder-clay. Wahnschaffe's conclusion that the *mer de glace* in question actually invaded the region lying south of the Elbe is considerably strengthened by Keilhack's discovery of an upper boulder-clay in the south of the Fläming—a district on the borders of Brandenburg and Anhalt.[4]

The same boulder-clay covers wide areas in Posen, but how far south it goes seems uncertain. Dr. J. von Siemiradski has traced it through the larger part of Poland,[5] its southern limits in that country being roughly indicated by a line drawn from south-west to north-east, from Radomsk, on the Warta, by Kielce, Radom, and Lublin, to Brest-Litovskii, on the Bug. From this point the southern margin of the clay in question continues to the north-east through the southern part of the Government of Grodno, and the extreme

[1] *Jahrb. d. königl. preuss. geolog. Landesanstalt f.* 1883, p. 238.

[2] *Zeitschr. d. deutsch. geol. Ges.* Bd. xl. p. 268.

[3] *Abhandl. z. geolog. Specialkarte v. Preussen*, &c. Bd. vii. 1885, p. 64. Laufer describes the 'upper diluvium' of the Luneburg Heath as 'diluvial sand, rich in erratics and gravel,' *Jahrb. d. köngl. preuss. geolog. Landesanstalt f.* 1883, pp. 310, 594.

[4] *Jahrb. d. königl. preuss. geolog. Landesanstalt f.* 1888, p. 123.

[5] *Jahrb. d. k. k. geol. Reichsanstalt*, 1889, Bd. xxxix p. 451; *Zeitschr. d. deutsch. geol. Ges.* Bd. xlii. (1890) p. 756.

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EURO

Plate X.

northern portion of the Government of Minsk.[1] North of this its limits have not been exactly defined. It would seem, however, to occur throughout all the regions that drain into the Baltic, and nowhere crosses the Ural-Baltic watershed, its terminal moraines appearing in the Valdai Plateau, which, with its rolling hillocks and numerous lakes, is described by Nikitin as a 'paysage morainique typique.'[2] From this point its margin probably strikes north by east, through Novgorod and Olonez to the shores of the White Sea. (See Plate X.) It is thus obvious that the 'upper boulder-clay' does not cover nearly so wide an area as the 'lower boulder-clay'—the latter extending to the foot of the mountains of Middle Germany and over a vast region in Central Russia, while the former goes no farther south than the sandy tract that lies between the Elbe and the Aller, and stretches no farther east than the Ural-Baltic watershed.

We must now consider the history of a remarkable series of terminal moraines, which are believed by most geologists to have been piled up by that ice-sheet underneath which the so-called 'upper boulder-clay' was accumulated. These moraines are confined to the Baltic coastlands, where they have been studied by Berendt, Eber, Geinitz, Hauchecorne, Jentzsch, Keilhack, Klebs, Klockmann, Nötling, Schröder, and Wahnschaffe in Germany, and by Sederholm, Frosterus, Ramsay, and Rosberg in Finland; by De Geer and others in Sweden and Norway, and by Meyn, Gottsche, Haas, and others in the Cimbric peninsula. From these authors we learn that the end-moraines in question circle round the southern coasts of Norway, from whence they sweep south-east by east across the province of Gottland in Sweden, passing through the lower ends of Lakes Wener and Wetter, while similar moraines mark out for us the terminal front of the inland-

[1] According to A. Gedroitz, two boulder-clays (the lower *grey*, the upper *brown*), separated by massive sheets of sand, &c., apparently unfossiliferous, occur over the region lying between Wilna and the river Pripet. Gomel on the Dnieper is the farthest point south to which he has traced the upper boulder-clay. (*Izviestija geologitjeskavo Kommiteta*, 1885, p. 345.) Nikitin, however, could find no trace of any upper boulder-clay in the lower reaches of the Pripet, nor in the upper part of the valley of the Dnieper, nor in the valley of the Sosch. *Ibid.* 1887, p. 25.

[2] *Izviest. geolog. Komm.* 1886, p. 133; 'Sur la constitution des dépôts quaternaires,' &c., *Congrès Intern. Archéolog.* Moscow, 1892.

ice in Finland—at least two parallel frontal moraines passing inland from Hango Head on the Gulf of Finland through the southern part of that province to the north of Lake Ladoga. Thence terminal moraines have been traced north as far as Lake Tuoppa and the shores of the Gulf of Kantalahti (White Sea). Between Sweden and Finland lies the basin of the Baltic, which at the period in question was filled with ice, forming a great Baltic glacier which overflowed the Åland Islands, Gottland, and Öland, and which, fanning out as it passed towards the south-west, invaded, on the south side, the Baltic provinces of Germany, while, on the north, it crossed the southern part of Scania in Sweden and the Danish islands to enter Jutland. Along the west of Norway the great fiords were at the same time occupied by glaciers, which do not appear to have extended beyond the general coast-line, but calved their icebergs there—erratics brought down from the interior being in this way floated away and stranded on other parts of the coast.[1]

There is no general agreement as to the extreme southern limits reached by the great Baltic glacier. It is admitted, however, that the ice-front made a long pause on the northern slopes of the Baltic Ridge, extending from west to east through Eastern Holstein, Mecklenburg-Strelitz, Uckermark, Neumark, Southern Pomerania, and the higher parts of West and East Prussia. If a good map be consulted it will be seen that this Baltic Ridge is a belt of land in which lakes and lakelets are abundantly developed—it is a true *paysage morainique*. The form of the surface differs considerably from that of the drift-covered regions immediately to the south and north, which are generally flat or gently undulating. The Baltic Ridge, on the other hand, is characterised by an irregular rolling surface—mounds, hummocks, and ridges of shingle, gravel, and sand, often associated with boulder-clay, being confusedly distributed over the whole region. In the depressions enclosed by those interosculating and irregularly distributed hillocks are lakes, bogs, and marshes innumerable. The deposits are recog-

[1] De Geer, *Zeitschr. d. deutsch. geol. Ges.* Bd. xxxvii. p. 177. When the erratics referred to were distributed the land stood, of course, at a lower level. See K. Pettersen, *Tromsö Museums Aarshefter*, vol. v. 1882, p. 73; De Geer, *Geol. Fören. Förh.* 1888, Bd. x. p. 195.

by German geologists as terminal moraines, and they arily indicate the position occupied for some considerme by the ice-front of a great Baltic glacier. The it association of boulder-clay with gravel and sand—ms of the hillocks and ridges, their confused bedding common occurrence of contortion and disturbance—icate accumulation at or near the terminal front of *de glace*. In their form, grouping, and structure the ocks and banks of gravel and sand, which I examined cermark and Mecklenburg, often recalled to me the of Scotland, while certain remarkable ridges which een followed for long distances are obviously true endles—comparable in origin to those of Alpine glaciers. are composed, for the most part, of boulders; hence n geologists describe them as 'Geschiebewälle' er-walls). Sand and boulder-clay, however, are not iently present, and occasionally the whole ridge s to consist of bedded gravel and sand, sprinkled atop rratics. Such end-moraines are best developed along ithern margin of the hummocky lake-dappled region. liately south of them the sand and gravel are rather out in wide sheets (*Sandr*) than heaped up into s and ridges.[1] This remarkable belt of morainic ulations is roughly concentric with the southern of the Baltic, from which it is separated by a more

descriptions of these moraines see Berendt, *Jahrb. d. königl. preuss. ndesanst. f.* 1887, p. 301; *ibid.* (with Wahnschaffe) p. 363; *ibid.*). 110; Geinitz, *I. Beitrag z. Geologie Mecklenburgs*, 1880, pp. 44, 56; *ugen z. d. Landes- u. Volkskunde*, vol. i. part 5 (1886); *Leopoldina*, 36), p. 37; *Zeitschr. d. deutsch. geol. Ges.* Bd. xl. p. 583; Wahnschaffe, *l. königl. preuss. geol. Landesanst. f.* 1887, p. 150; *Verhandl. d. eutsch. Geographentages z. Berlin*, 1889, p. 134; *Forsch. z. deutsch. u. Volkskunde*, Bd. xi. p. 103; Keilhack, *Jahrb. d. k. k. preuss. ndesanst. f.* 1889, p. 142; Haas, *Die geologische Bodenschaffenheit g-Holsteins*, &c. 1889, p. 131. For the moraines of Southern see Vogt, *Förh. i Vid. Selsk. i Christiania*, 1881, No. 8, p. 1; De *ol. För. Förh.* Bd. vii. p. 436; Törnebohm, *Sveriges Geol. Undersökn.* Sheet 37; Karlsson, *ibid.* Expl. of Sheet 33. For the terminal of Finland see *Fennia*, vol. i. No. 7; vol. iii. No. 8; vol. iv. No. 2; No. 2. These resemble generally the moraines of the Baltic Ridge. points out that there are two systems of glacial striæ in Finland—an l a younger. The latter system is bounded by the zone of terminal i. These consist partly of ground-moraine, partly of water-worn s. Some are largely composed of gravel and sand, or of shingle and , while others are made up of angular blocks and débris. Sheets of nd sand spread outwards from the moraines, and are obviously similar to the 'Sandr' of Iceland.

or less broad band of low flat land, consisting chiefly of boulder-clay, overlaid in places by interrupted sheets of sand and alluvium, and traversed here and there, in various directions, by well-marked åsar. In short, the morainic accumulations in question bear the same relation to the Baltic as the terminal moraines of Scotland and the Alpine Lands do to the great lakes of those regions. The materials composing the morainic mounds and banks of the Baltic Ridge would seem to have been accumulated partly underneath the terminal portion of the *mer de glace* and partly immediately in front of the ice as true 'end-moraines.' That water has played an important rôle in the formation of the deposits cannot be doubted since these are largely composed of sand and gravel. The present configuration of the hillocks and mounds, like that of our own hummocky kames, is no doubt original—that is to say, it dates back to the time of their formation. But they have not all been heaped up in the form which they now show. In certain places they consist of horizontally disposed beds, the abrupt truncation of which points to erosion. Thus some of the rolling hills in the neighbourhood of Angermünde (Uckermark) appear to consist largely of horizontal finely laminated sand, often showing diagonal bedding. Amongst this sand layers of clay and bands of gravel occur, and now and again stones and large blocks are common. Many of these are more or less water-worn, others are angular or subangular, and not a few are smoothed and striated. Such blocks appeared to be most abundant on the tops of the sand-hills. It seemed to me that in this district some of the sand, &c., had been laid down in the form of a gently undulating sheet by subglacial water under the terminal portion of the ice-sheet; and that, during the subsequent retreat of the ice-front, the fluvioglacial deposits were subjected to erosion by the water of ablation. It must further be noted that such water-arranged deposits not infrequently interosculate with boulder-clay, so as to show that both were accumulated side by side underneath the peripheral or marginal area of the *mer de glace*. The confusion and disturbance they sometimes exhibit may well be attributed to the forward push and drag of the ice. With the analogy of modern glaciers before us we may

ıdily believe that the ice-front may have oscillated to and ı for a long time on the Baltic Ridge, ever and anon .shing forward or even over-riding its frontal moraines and agging subglacial detritus above them. Probably no in-nsiderable part of the materials has thus been worked over but while this may well have been the case, it would seem rtain that a large proportion of the hills and banks of avel and sand have originated much in the same way as the ottish kames and the gravelly moraines of Alpine regions. ıe distribution and disposition of the German kames show at the great Baltic glacier terminated with an irregularly ɔate margin. In the spaces between adjacent ice-lobes ıter-action was always vigorous, and we see the result in e formation in such places of conspicuous hills of sand and ıvel. But the whole ice-front, for long distances, appears have been margined, and was probably in part overlaid by nilar fluvio-glacial accumulations and erratics. Thus when ɜ *mer de glace* finally melted away, those accumulations me to form winding belts of hills and banks, ridges and mmocks, showing intervening depressions of irregular form d extent. Much of the confusion and disturbance seen the bedded deposits may well be assigned to the settling wn of the materials while the ice was melting.[1] The ɜrman kames, in a word, are true gravelly moraines. It ɔuld seem certain also that the long lines of 'boulder-walls' e end-moraines that never were over-ridden. During their rmation the ice-front must have maintained its position r some time. They are, in short, true end-moraines, mposed partly of materials extruded from underneath the ɜ, and partly of débris melted out of its lower portion or ashed down from its surface. We cannot doubt, therefore, at German geologists are justified in their belief that the

[1] The disturbance and contortion so often seen in the sand and gravel of e Baltic Ridge may not unlikely owe their origin in some cases to the melting embedded or subjacent sheets and masses of frozen snow. One can hardly ubt that during glacial times the snows of winter may have drifted over the andr' in front of the ice-sheet, and become accumulated to great depths in llows which would subsequently be overspread by fluvio-glacial detritus. But e confused structure seen in the true kames is most probably due to the ice the peripheral area being in many places more or less deeply buried under .vio-glacial morainic débris - the subsequent melting of the ice causing the erlying bedded gravel and sand, &c., to settle down confusedly.

'boulder-walls' in question were accumulated during the final retreat of the great Baltic *mer de glace*. Some, indeed, are of opinion that not only the conspicuous boulder-walls, but all the hummocky morainic materials of the Baltic Ridge, belong to the same period of retreat. This view, however, is not shared by Professor Wahnschaffe, who, while admitting that the boulder-walls are moraines of retreat, thinks it probable that the great belts of hummocky moraines were accumulated by the *mer de glace* during its period of advance. He supposes that when the ice first emerged from the basin of the Baltic, and began to creep up the opposing slopes, its motion would be retarded, and that this retardation would induce excessive accumulation of subglacial débris. It was thus, he thinks, that the far-extended hummocky moraines of the Baltic Ridge came into existence. In common with other German geologists he is of opinion that the great Baltic glacier eventually overtopped the Ridge and flowed south to the valley of the Elbe, and hence he is under the necessity of supposing that the moraines of the Baltic Ridge must have been deeply drowned in ice, and while thus drowned succeeded in preserving their peculiar configuration. During some recent traverses of the Baltic *paysage morainique* I came to the conclusion that that region has never been overflowed by ice since the moraines in question were heaped up—a view which has also been expressed by Dr. Keilhack and Professor Salisbury. The advance of a *mer de glace* across the Baltic Ridge must have resulted in the demolition of mounds and hummocks and in the wholesale redistribution of their materials. The only reasonable conclusion is that all the hummocky moraines, together with the boulder-walls, belong to one and the same stage—they mark the former margin of a great Baltic glacier, which after maintaining its position on the Baltic Ridge for some time eventually retreated.

We have now to consider an important question. Do the moraines of the Baltic Ridge pertain to the general horizon of the 'upper diluvium'? Or, to put it more closely, are the 'upper boulder-clay' of the neighbourhood of Berlin and the lower valley of the Elbe, and the terminal moraines of the Baltic Ridge, the products of one and the same *mer de*

glace? So far as I can gather, this is the general opinion. Most German geologists hold that the great Baltic glacier flowed south as far at least as the valley of the Elbe. During its advance and retreat the upper diluvium of those regions is believed to have been formed. When at last it had retired to the Baltic Ridge it made, as they suppose, a considerable pause, and there accumulated the great terminal moraines before it finally disappeared. This at first sight seems a reasonable view, but when we come to correlate the evidence strong doubts arise as to whether that evidence has been correctly interpreted. I cannot help feeling that the use of the terms 'upper' and 'lower' as applied to the boulder-clays of Northern Europe has been misleading—that the upper boulder-clay of one region has been assigned to the same horizon as the upper boulder-clay of other countries simply because of its superficial position. I have not met with any evidence, either upon the ground or in the writings of German geologists, to prove that the upper boulder-clay which extends north from the terminal moraines of the Baltic Ridge to the shores of that sea is of the same age as the upper boulder-clay that stretches south from the moraines in question to the valley of the Elbe. Their identity has simply been taken for granted. Nor is this to be wondered at, for over wide regions both clays are charged with much the same assemblage of erratics—petrographically the one can hardly be distinguished from the other. Both, in short, are the ground-moraines of a glacier which has flowed out of the Baltic. And yet, as I shall endeavour to show, the two boulder-clays are the products of two separate and distinct *mers de glace*.

It has already been pointed out that the 'upper boulder-clay' extends in Germany far beyond the limits of the Baltic Ridge. As it also stretches south much farther than the great terminal moraines of Finland, it is obvious that the Baltic glacier underneath which that upper boulder-clay accumulated must have greatly exceeded in dimensions the glacier which left its terminal moraines in Southern Sweden, Eastern Jutland, the Baltic provinces of Germany, and Finland. Take another consideration. We have seen that the lower and upper boulder-clays of Middle and Western

Germany are distinguished from each other chiefly by means of their included erratics. The stones and boulders of the older deposit indicate an ice-flow from north to south. In short, the older till is the ground-moraine of an ice-sheet that flowed in a general southerly direction across Denmark, Holland, and North Germany. Now the erratics in the 'upper boulder-clay' of Middle and Western Germany denote on the other hand a glacial movement from east to west (or from east by north to west by south), that is, nearly at right angles to the course followed by the earlier *mer de glace*. These are striking facts, and if the lower and upper boulder-clays of the Baltic coast-lands are the representatives of the two stony clays of Middle and Western Germany, they ought to be similarly distinguished. The lower ought to be crowded with erratics which have travelled in a general southerly direction—the upper should be charged with stones and boulders derived chiefly from the east and north-east. We may take Schleswig-Holstein as a crucial case. In this region an upper and a lower boulder-clay have long been recognised. Both occur along the eastern section of that country, to which the upper is confined, while the lower extends westward to the shores of the North Sea. Now if this latter be the product of the great ice-sheet which flowed south from Scandinavia, and deposited northern erratics in Holland,[1] it is obvious that it ought to be largely composed of materials which have had a similar origin. Such, however, is not the case. Dr. Zeise tells us[2] that

[1] In Holland only one boulder-clay occurs, that, namely, of the maximum glaciation (J. Lorié, *Ann. de la Soc. géol. de Belg.* t. xiii. (1886) p. liii.; Prof. van Capelle, *Bull. de la Soc. Belg. de Géol. Palæont.* &c. t. ii. (1888) p. 125). The same is the case in Oldenburg (K. Martin, *Abhandl. d. naturwiss. Vereins zu Bremen*, Bd. vii. Hft. 3), and farther south in the neighbourhood of Osnabrück (Hamm, *Zeitschr. d. deutsch. geol. Ges.* Bd. xxxiv. (1882) p. 629). In all those regions the boulder-clay consists partly of native, partly of northern materials, and the direction of transport of both indicates an ice-movement from the north. It ought to be mentioned, however, that in Groningen, in the extreme north of Holland, the boulder-clay yields a considerable number of erratics derived from Finland and North and Middle Sweden, which, according to Professor F. J. P. van Calker, are probably *remaniés*—derived from the morainic accumulations of the first great Baltic glacier, as described by Nathorst and Lundbohm. (*Zeitschr. d. deutsch. geol. Ges.* 1889, p. 343.) See also papers by same author, *op. cit.* 1889, p. 385; 1890, p. 578; 1891, p. 792; *Handelingen van het Vierde Nederl. Natuur en Geneeskundig Congres*, April 1893.

[2] 'Inaugural Dissertation,' *Albertus Universität zu Königsberg in Preussen*, 1889, p. 31.

the lower and upper boulder-clays of Schleswig-Holstein contain the same assemblage of erratics—both deposits have been laid down by ice coming from the east. The one cannot be distinguished from the other by petrographical characters. These facts serve to show that the so-called 'lower boulder-clay' of the Cimbric peninsula cannot be the equivalent of the 'lower boulder-clay' of Western and Middle Germany. The former is the ground-moraine of an ice-sheet that moved outwards from the Baltic basin in a westerly direction—the latter is the product of the vast *mer de glace* that flowed south into Saxony, the two cannot be correlated—they belong to separate and distinct stages of the Glacial Period. The 'lower boulder-clay' of Schleswig-Holstein is obviously the equivalent of the 'upper boulder-clay' of Western Germany, while the younger boulder-clay of the Cimbric peninsula occupies the horizon of the terminal moraines and upper boulder-clay of the Baltic provinces of Prussia.[1] The recent researches of Dr. Weber seem to me to have put this beyond doubt; for he has shown that in Central Holstein the so-called 'lower boulder-clay' of Dr.

[1] Dr. Zeise is puzzled to account for the easterly transport of erratics in what he calls the 'lower boulder-clay' of Schleswig-Holstein, for if that deposit were the equivalent of the lower boulder-clay of Western Germany, &c., it ought to afford clear evidence of an ice-flow from north to south. His explanation of the apparent anomaly is that the boulder-clay of Holland and the 'lower' boulder-clay of Schleswig-Holstein were accumulated at successive stages of one and the same Glacial Period. Following Dr. Torell, he surmises that the *mer de glace* of the maximum glaciation must first have existed as a great Baltic glacier overflowing Schleswig-Holstein from east to west. Afterwards, when it reached its full development, its course over the Cimbric peninsula would be southerly. Lastly, during its decline, it would again assume the appearance of a great Baltic glacier, flowing from east to west as before. It is, of course, quite natural to suppose that the ice-sheet in question may have passed through these successive stages; but although it may well have existed in its early days as a great Baltic glacier, there is no reason to believe that it resumed that character when the period of final dissolution ensued. Neither in our own country nor in other formerly glaciated regions is any evidence forthcoming to show that great *mers de glace* disappeared in that way. All the facts indicate that when dissolution had fairly set in, the general motion of the ice over low-lying tracts was arrested, and the *mer de glace* melted away continuously, and perhaps rather rapidly. I formerly thought otherwise; but many years ago when following the upper boulder-clay of Scotland from the low grounds into the mountain-valleys, I found that the facts would not square with what does at the first blush seem a not unreasonable supposition. If the motion of the ice had not been arrested in the low grounds during dissolution it would be difficult to account for the well-preserved aspect of subglacial åsar and eskers. It seems to me most probable, also, that it was during this stage that the remarkable 'giants' kettles' and 'Sölle' of the plains of North Germany were formed.

Zeise is underlaid by a yet older boulder-clay from which, as already described, it is separated by interglacial deposits. Thus in Holstein we have three separate and distinct boulder-clays—the youngest confined to the eastern margin of that region, and obviously related to the hummocky moraines of the Baltic coast-lands; the second extending west to the North Sea, and overlying and concealing the third boulder-clay, which is only revealed in deep cuttings.

Turning now to Finland and the adjacent tracts of Russia, clear evidence is forthcoming to show that the end-moraines of those regions mark the extreme limits reached by the last great Baltic glacier. Rosberg tells us that two distinct systems of glacial striæ are apparent. The striæ of the one system run in parallel directions, and extend far east and south-east of the terminal moraines. The other and younger system, on the other hand, is bounded by these moraines—the later striæ crossing the older series at various angles. When striæ belonging to both systems appear on one and the same rock-surface, the younger are always the fresher of the two—the older ones being worn and abraded. The latter, according to Rosberg, are the products of a general *mer de glace*, which attained so great a thickness that minor inequalities of the ground had little or no influence in deflecting the ice-flow, which extended far beyond the limits of the terminal moraines. The ice underneath which the younger system of striæ came into existence must have been relatively thin, in consequence of which the inequalities of the ground produced endless local divergences from the general direction of ice-flow.[1]

Let me now recall to the reader's remembrance the evidence bearing on the conditions that obtained in the North Sea area during the accumulation of the upper boulder-clay of Eastern Britain. The distribution of that boulder-clay, the trend of its erratics, and the direction of the rock-striæ underneath it, show clearly that the passage of the British

[1] Reference may be made here to the similar occurrence of two sets of striæ in the island of Gottland, the older trending from NE. to SW., the younger from N. to S., or a little west of N. to east of S. (T. Fegræus, *Geol. Fören. Förhandl.* 1886, Bd. viii. p. 158). Similar observations have been made on the coast-lands of Norrbotten, between Piteå and Luleå, where two systems of striæ are seen, one of which trends from NW. to SE., and the other from NNW. to SSE. (K. A. Fredholm, *op. cit.* 1892, Bd. xiv. p. 195).

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To face page [illegible] *Plate VI.*

ea was opposed by the presence of the Scandina- glace. In short, the British and Scandinavian were coalescent during the formation of our upper y. Such having been the case we ought to have tal representative of that deposit. The terminal f the Baltic Ridge and the upper boulder-clay that m that ridge to the shores of the Baltic cannot be ents of the upper boulder-clay of Eastern Britain. leposit with which the latter can be correlated is boulder-clay that lies south of the hummocky &c., of the Baltic Ridge. With this interpretation lence obscurities and difficulties disappear, and succession on the Continent tallies precisely with ir own islands. Thus our lower boulder-clay s to the ground-moraine of the lower diluvium ks the epoch of maximum glaciation. The upper y of Britain represents in like manner the upper y of Western and Middle Germany, of Poland, Russia, while our large terminal moraines and und-moraines in mountain areas are on the same horizon as the terminal moraines of Southern nland, and Russia—the similar moraines of the lge, and the upper boulder-clay that extends ese and the Baltic in Denmark, Schleswig-Hol- lenburg, Uckermark, Pomerania, and West and ia. The terminal moraines of the Baltic Ridge, nland, &c., mark the southern limits reached by at *mer de glace.* (Plate XI.)

n the low grounds of North Germany, &c., we round-moraines of three separate *mers de glace.* e first was the greatest—reaching to the foot of he Erz-Gebirge, &c. The second did not cover area, but it flowed some 40 miles south of Berlin its terminal front in Western Germany being pro- sented by the sands and erratics that extend to vest through Altmark and the Lüneburg Heath in nover. The direction of ice-flow in Brandenburg s south-west—the trend becoming more westerly er reaches of the Elbe were approached. The ninsula was traversed from north of east to south

of west, the ice-sheet flowing outwards into the basin of the North Sea. It is impossible, of course, to say in what particular direction the ice-front extended across that basin to unite with the British *mer de glace*. The latter, as we know, hugged the coast of Lincolnshire--in other words, its course was south-east along the maritime parts of East England. Possibly the ice-front of the united *mers de glace* was somewhat irregular, as shown upon the sketch-map (Plate X.) where a broad tongue of ice is represented as extending between the English coast and the Dogger Bank, the ice-front thereafter sweeping round the latter, and curving in a south-east direction to the low grounds between the Weser and the Elbe. I need not attempt to trace in detail the direction of the ice-front of this lesser *mer de glace* across Germany, through Poland into Russia. We have seen that its ground-moraine covers a large part of Poland and the Baltic provinces of Russia—the area occupied by the ice being indicated on Plate X.

A glance at a good map will show that south of the terminal moraines of the Baltic Ridge and those of Finland and Russia lakes are still very numerous. Witness the large lakes of Peipus, Ladoga, and Onega, and the countless sheets of water that are sprinkled over all Northern and Western Russia. Lakes are very common also in Posen and in South Brandenburg. South of the regions occupied by the upper boulder-clay of Middle Germany, &c., they appear to be of less frequent occurrence. In short, lakes are least common in those tracts where the boulder-clay of the lower diluvium only is present. They are more abundant in regions where the boulder-clay of the upper diluvium appears at the surface, but reach their greatest development in the tracts which are margined by the terminal moraines of the last great Baltic glacier. This lake-distribution seems to afford a rough test of the relative antiquity of the three sets of glacial accumulations. Lakes are few in number in countries occupied by the oldest deposits, since sufficient time has elapsed to allow of their obliteration by erosion of their outlets, or by silting-up and other superficial changes. They are most abundant, in short, in the regions which have been most recently subjected to glaciation.

But it may be objected that if the diluvial deposits of North Germany, &c., are the morainic accumulations of three separate glacial epochs, we might expect to encounter in the Baltic coast-lands more direct evidence of this. If those lands have been subjected to three glacial invasions, we might now and again meet with three boulder-clays in superposition one upon the other. It is true that each incursion of an ice-sheet would result in the demolition and re-arrangement of the loose accumulations that lay in its path, and in the concealment under its own ground-moraine of such deposits as chanced to escape destruction. But, on the other hand, it is obvious from the great thickness attained by the drift-accumulations of the Baltic coast-lands and the low-grounds of North Germany that these were regions rather of deposition than erosion. There, if anywhere, therefore, we might expect to discover traces of each successive glacial invasion. Now, as we have already seen, a lower and an upper boulder-clay do occur throughout all the Baltic coast-lands which have been carefully explored. Not only so, but in some places three and even four boulder-clays have been recognised by such excellent observers as Jentzsch, Ebert, Klebs, and Schröder.[1] These clays, they tell us, are distinctly marked off from each other, and have been followed over wide areas, and they are separated by fossiliferous aqueous deposits. It is conceivable, of course, that all these boulder-clays may be products of one epoch, laid down during more or less considerable oscillations of an ice-sheet. In this view of the case, the intercalated fossiliferous deposits indicate temporary retreats, while the boulder-clays denote successive re-advances of one and the same *mer de glace*. This is the usual explanation, but so far as the evidence of the actual sections themselves is concerned, it cannot be denied that the boulder-clays with their intercalated fresh-water beds may just as likely represent so many distinct glacial and

[1] These boulder-clays occur in the Baltic provinces of Prussia. They are not confined, however, to those districts. The so-called lower boulder-clay of the island of Rügen consists (according to M. Scholtz) of two separate sheets with intervening beds of sand (*Jahrb. d. königl. preuss. geol. Landesanstalt f.* 1886, p. 32), while in the neighbourhood of Greifswald on the mainland (Mecklenburg) E. Bornhoft has likewise described the occurrence of three boulder-clays (*II. Jahresbericht d. geograph. Ges. z. Greifswald*, 1883–84).

interglacial epochs. It is very suggestive, moreover, that south of the Baltic Ridge no more than two boulder-clays are ever met with, while in the regions south of the Elbe the enormously deep glacial accumulations show only one boulder-clay. These appearances cannot be accidental. If only one boulder-clay appears in Saxony, it is because that country was invaded only once. If two boulder-clays occur between the valley of the Elbe and the Baltic Ridge, these are evidence of two successive glacial invasions. If three or more boulder-clays overspread the Baltic coast-lands we may reasonably infer that those lands have been subjected to glaciation more frequently than the regions lying to the south.[1] In short, the evidence is strongly suggestive of at least three and probably of four successive glacial invasions of the Baltic coast-lands, as follows:—

1. During the existence of the earliest great Baltic glacier, the ground-moraine of which was first recognised by Nathorst;

2. During the epoch of maximum glaciation, when the ice flowed south into Saxony;

3. During the succeeding epoch of lesser glaciation, when the ice-sheet extended south to the Lüneburg Heath;

4. During the incursion of the last great Baltic glacier, when the ice did not advance beyond the Baltic Ridge.

[1] In connection with this question it is noteworthy that upon the exposures of the chalk of Faxö in Seeland three systems of rock-striæ have been described by Forchhammer (*Oversigt over det D. Vidsk. Selskabs Förhandl.* for 1843) and Johnstrup (*Inbydelsesskrift till Kjöbenhavns Universitets Fest, &c.* 1882). The youngest system indicates an ice-movement from east to west and south to north; the second from south-east to north-west and east to west; the third from south-east to north-west and south to north. The distribution of erratics of Faxö chalk in the glacial deposits is quite in keeping with the evidence of the striæ. But fragments of the same rock occur in the island of Langeland and at Rendsborg in Central Holstein, whither they could only have been transported by an ice-movement from north-east to south-west. Again two systems of striæ are met with in Askö and Svansbjerg (Laaland), which trend respectively from south-east to north-west, and from south to north, while at Lellinge the direction is from east-north-east to west-south-west (Johnstrup, *op. cit.* p. 45). The last-named obviously belongs to the epoch of maximum glaciation. None of the three systems observed in Seeland can be of this age—each indicates the direction of movement of a great Baltic glacier. The freshest marks (which sometimes cross the others on the same glaciated surface) obviously were engraved by the last Baltic glacier. At what period were the fainter and older striæ imprinted on the rocks? Some of them, one is inclined to believe, may belong to the epoch of the 'lesser glaciation' (= epoch of lower boulder-clay of Baltic coast-lands and upper boulder-clay of Western and Middle Germany), while the very faintly-marked system, which is apparently older than the other two, may possibly indicate Nathorst's early Baltic glacier.

This succession, it will be noticed, exactly harmonises vith that observed in Britain. It is true we have no recognisable boulder-clay on the horizon of the earliest Baltic glacier, but we have the evidence of cold conditions in the Weybourn Crag with its arctic fauna, which I take to be the equivalent in time of the oldest boulder-clay in Southern Sweden.

I may now briefly sum up the conclusions to which this discussion has led me :—

1. *Epoch of Earliest Great Baltic Glacier.*—Lowest oulder-clay in Southern Sweden. (Horizon of Weybourn rag in Britain.)

2. *Interglacial Epoch.*—Peat and fresh-water beds under e Lower Diluvium of Western and Middle Germany. Iorizon of Cromer Forest-bed.)

3. *Epoch of Maximum Glaciation.*—Lower boulder-clay Holland, North and South Germany, Poland, and Central ussia. (Lower boulder-clay of Britain.)

4. *Interglacial Epoch.*—Peat and fresh-water beds of entral and Southern Holstein, Brandenburg, and Central Russia. Marine and fresh-water deposits underlying the so-called 'lower boulder-clay' of the Baltic coast-lands. (Interglacial beds of Britain, as in Central Scotland, NW. and NE. England, &c.)

5. *Epoch of Lesser Glaciation.*—'Lower boulder-clay' of Baltic coast-lands; upper boulder-clay of Central and Southern Holstein, Western and Middle Germany, and West-Central Russia. (Upper boulder-clay of Britain.)

6. *Interglacial Epoch.*—Marine and fresh-water beds ccurring between the so-called 'lower' and 'upper' boulder-lays of the Baltic coast-lands. (Probably some portion of he so-called 'postglacial' alluvia of Britain.)

7. *Epoch of Last Great Baltic Glacier.*—So-called 'upper oulder-clay' of Baltic coast-lands. Great terminal moraines f South Norway and Sweden, of the Baltic Ridge, and of inland and Russia. (District ground-moraines and large alley-moraines of British mountain regions.)

CHAPTER XXXI.

GLACIAL PHENOMENA OF NORTHERN EUROPE—*continued.*

Åsar—Seter-lakes—Position of Scandinavian ice-shed—Evidence of submergence; Strandlinier; Arctic shell-beds—Re-elevation—Arctic plant-beds—The Baltic a fresh-water lake—Immigration of flora—Re-submergence; littorina-beds—Later glaciers—Dr. Hansen's views—Professor Blytt's observations on Scandinavian peat-bogs and tufas—General résumé.

WE must now pass rapidly in review the accumulations of later date than the upper boulder-clay of the Baltic coast-lands. We have already learned that each individual ice-sheet during its final disappearance left its ground-moraine strewn with heaps and sheets of sand and gravel and dotted with erratics. Hence each boulder-clay is associated with overlying aqueous accumulations, and the boulder-clay of the last great Baltic glacier is no exception to the rule. The regions formerly occupied by that *mer de glace* show not only fresh *roches moutonnées* and glaciated rock-surfaces, but wide sheets of till more or less deeply covered in places with sand and gravel, while erratics large and small are sprinkled everywhere. Among the most remarkable deposits overlying the youngest boulder-clay of Scandinavia, Finland, and North-west Russia are certain great natural embankments or long winding ridges, which are known generally by the Swedish name åsar.[1] They sometimes rest upon boulder-clay, but oftener perhaps upon solid rock, and form very striking features, rising abruptly as they do to a height that may vary from 50 to 100 ft. above the average surface of the ground. Sometimes, however, they reach as much as 180 ft., while now and again they sink to 30 or 20 ft., or even disappear altogether below newer deposits. Their sides have an inclination of from 15° to 20°, but occasionally as much

[1] Ås, singular; åsar, plural.

25° or even 30°, and the two declivities very rarely slope the same angle.[1]

Often beginning in the interior of the country, the åsar llow the valleys down to the low coast-land, across which

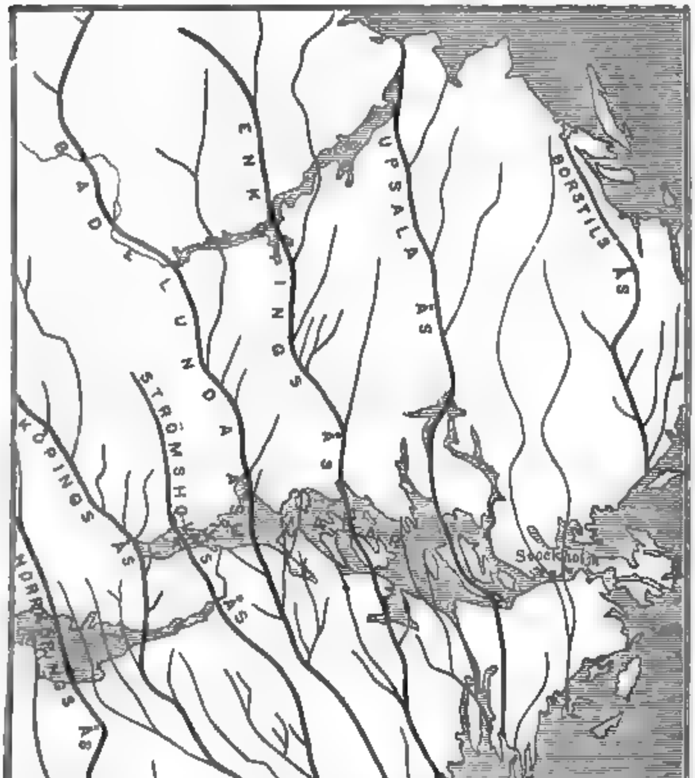


Fig. 75.—**Map** of Åsar in basin of Mälar Lake.

ey pass as well-defined ridges out to sea, after a course of t infrequently more than a hundred English miles.[2] In the ode of their distribution they show a striking resemblance

[1] *Exposé des Formations quaternaires de la Suède*, par A. Erdmann, pp. 61.

[2] Erdmann mentions as examples, Upsala ås, which is about 200 kilometres length; Köpings ås, very nearly 240 kilometres: Enköpings ås, 300 to 340 ometres; Badelunda ås, about 300 kilometres. *Op. cit.* p. 44.

to river-courses, as will be seen from the accompanying sketch-map, on which the black lines represent the åsar.[1]

At greater heights than 300 ft. above the sea these remarkable ridges are, as a general rule, confined to the valleys, but at lower levels they seem to be tolerably independent of the present configuration of the ground. They are met with at all levels up to and above 1,000 ft.[2] The materials of which they are composed may consist either of coarse shingle, or of pebbly gravel, or of sand, or it may be made up of all three. In some parts of a ridge shingle and gravel predominate, in others sand is the principal ingredient. In one place the stratification may be distinct, in other places obscure, and not infrequently diagonal bedding appears. Åsar are not confined to Scandinavia; excellent examples occur in Russia and Finland, where they have been studied by Helmersen,[3] Kropotkin,[4] Berghell, Sederholm, and others,[5] and they have been recognised also in North Germany.[6]

There has been much speculation as to the origin of these remarkable ridges. Sefström attributed their origin to a great diluvial flood,[7] while at a later date they were considered by Ch. Martins to be marine accumulations [8]—a view which for some time Robert Chambers advocated,[9] although he subsequently inclined to the belief that they are moraines. A. E. Törnebohm thought they were the relics of old river-beds formed after the disappearance of the ice-sheet.[10] According to

[1] The map is from a paper by A. E. Törnebohm in *Geol. Fören. i Stockholm Förh.* Band i. No. 4.

[2] The highest mentioned by Erdmann occurs at Herjeådal, between 1,300 and 1,400 ft. above the sea, but Dr. Törnebohm informed me that in the mountain-valleys of the north they go up to elevations of over 2,000 ft.

[3] *Mémoires de l'Acad. impér. des Sciences de St.-Pétersbourg*, vii[e] Sér. t. xiv. No. 7, p. 92.

[4] *Izviestija Imp. rosskoi Geographitcheskago Obschestva*, t. vii. 1876.

[5] *Fennia*, 1889, p. 1, No. 7; 1892, p. 5, Nos. 2, 3; see also Rosberg, *op. cit.* 7, No. 2.

[6] F. E. Geinitz, *Zeitschr. d. deutsch. geol. Ges.* 1886, p. 654; *Archiv d. Vereins d. Freunde d. Naturgesch. in Mecklenburg*, 1885, p. 91; 1886, p. 115; *Forschungen z. deutsch. Landes- u. Volkskunde*, Bd. i. (1885) p. 11; *XIV. Beitrag zur Geologie Mecklenburgs*, 1892; G. Berendt, *Zeitschr. d. deutsch. geol. Ges.* 1888, p. 483; H. Schröder, *Jahrb. d. königl. preuss. geol. Landesanst. für* 1888, p. 166; Wahnschaffe, *ibid.* 1890, p. 278.

[7] *Poggendorfs Annalen der Physik und Chemie*, 1836, p. 614.

[8] *Bull. de la Soc. géol. de France*, 1845, 1846.

[9] *Tracings in the North of Europe*, 1850, p. 238 *et passim*; *Edinb. New Phil. Journ.* 1853, p. 229.

[10] *Geol. Fören. i Stockholm Förh.* Bd. i. No. 4; *Geol. Mag.* 1872, p. 207.

David Hummel, however, the åsar mark the sites of subglacial tunnels, and similar views have more recently been advocated by P. W. Strandmark,[1] whose observations have added considerably to our knowledge of these remarkable ridges. Hummel's views I have already discussed (Chap. XIV.), and in drawing attention to Herr Strandmark's interesting work, I need only mention here that he well explains the origin of the 'gravel flat' which is so frequently associated with the lower end of an ås. All the facts adduced by him go to show that the åsar occupy the sites of subglacial tunnels, as Hummel was the first to suggest. The terminal gravel-flats, on the other hand, were formed by the rivers after they issued from underneath the ice. They are comparable, in short, to the 'Sandr' of Iceland, to which reference has already been made. Dr. Holst's theory having been discussed in Chap. XIV., need not be further referred to. It is unquestionably a suggestive explanation, and may possibly be applicable in some cases, but the views advocated by Hummel and Strandmark seem upon the whole to be the more satisfactory.[2] Whatever the particular origin of the åsar may have been we are justified in assigning the formation of most to the time when the last great Baltic glacier was melting away.

To this same period belong certain high-level plains and terraces which appear upon the plateaux and in the upper reaches of many mountain-valleys on the east side of the water-parting or backbone of Scandinavia. These 'seter,' as they are termed by the country folk, appear in valleys as well-marked terraces, varying from ten yards or less up to 100 yards or thereabout in breadth. They show usually a smooth even surface, and, forming as they do stretches of green meadow-land, contrast strongly with the dark rocky mountain-

[1] *Redogirelse för h. allur. lörvverket i Helsingborg läsåret*, 1884-85. See also *Neues Jahrb. für Min. Geol. u. Pal.* 1887, Bd. i. p. 62 (Ref.).

[2] So long ago as 1867 C. W. Paijkull described the occurrence of åsar in Iceland. One of these he observed at the lower end of the existing glacier (Solheima Jökull) in the valley of the Fúlilaekr. It was some 50 ft. in height, and extended for several hundred yards from the end of the glacier in the same direction as the river. Paijkull was convinced that this bank was neither a medial moraine nor the relics of a deposit cut down by the Fúlilaekr. ('Bidrag till Kännedomen om Islands Bergsbyggnad,' *Konigl. Svenska Vetensk.-Akad. Handl.* Bd. vii. (1867-68) No. 1, p. 15.) When Dr. Keilhack visited the Solheima Jökull in 1883 this interesting ås had disappeared—having probably been demolished, as he suggests, by an advance of the glacier. (*Zeitschr. d. deutsch. geol. Ges.* 1886, p. 444.)

slopes against which they abut. Dr. A. M. Hansen recognises two kinds, namely, *Engseter*, which are built up of loose superficial materials, and *Bergseter*, which are mere shelves excavated in hard rock. The former consist, as a rule, of well-rolled gravel and sand—sometimes the one, sometimes the other predominating. The stones of the gravel seldom exceed one's fist in size, while larger blocks are of very rare occurrence. The terraces are approximately horizontal. They have no resemblance to glacial moraines, nor could they have been deposited in still water between the flank of a glacier and the mountain-side, for had such been their origin they must have contained morainic materials and much angular débris with larger fragments launched from the contiguous glacier-slopes. According to Dr. Hansen,[1] these 'seter' are the relics of glacial lakes, some of which must have extended over wide areas. As we have already seen, the ice-shed of the Scandinavian *mer de glace* did not coincide with the true divide or water-parting of the country.[2] In point of fact it lay 70 to 100 miles to the east and south-east. These were the conditions that obtained during the climax of glacial cold, and a similar state of things existed at the time when the last great Baltic glacier attained its maximum development. Hence it came to pass, as the surface of the latest *mer de glace* was lowered by ablation, the dominant divide or water-parting began to appear, and great lakes came into existence in the upper reaches of the mountain-valleys, as in Osterdal and Gudbrandsdal. Into these lakes, gravel, sand, &c., were swept by the water escaping from the surrounding ice-covered tracts. It is probable that at the time such lakes appeared glacier-ice yet filled the upper reaches of many of the mountain-valleys descending to the east and south-east. In other words, the lakes at first need not have been very deep—their bottoms being formed partly of rock and partly of glacier-ice. As the great ice-dam was

[1] *Archiv. for Mathematik og Naturvidenskab*, Bd. x. (1885), xiv. xv. (1891); *Om beliggenheten av bræskillet og forskellen mellem kyst- og kontinental-siden hos den Skandinaviske storbræ*, 1893; *Menneskeslægtens Aelde*, 1894.

[2] Hörbye's observations, referred to at p. 424, have been fully confirmed by later investigation. See especially De Geer, *Geol. Fören. Förh.* Bd. vii. p. 436; *Zeitschr. d. deutsch. geol. Ges.* Bd. xxxvii. p. 177 (a translation of the preceding); *Geol. Fören. Förh.* Bd. x. p. 195; A. M. Hansen's papers already cited; and K. A. Fredholm, *Geol. Fören. Förh.* Bd. xiv. p. 195.

lowered by ablation the levels of the seter-lakes would necessarily fall. And thus we have no difficulty in understanding how a succession of terraces would be formed, until the final dissolution of the *mer de glace* brought the seter-lake epoch to a close.

Professor Schjötz does not agree with Hansen that the ice-shed could have been maintained to the east of the water-parting during the later stages of glaciation. He thinks that as the *mer de glace* diminished the ice-shed would gradually retreat westwards until it came to coincide with the true divide or backbone of the country.[1] In short, his view is that a *mer de glace* in the later stages of its dissolution becomes resolved into a series of local glaciers flowing from the dominant ridges of the land. Now if such had been the case with the *mer de glace* of which I am speaking, we should have direct evidence to show that the ice-shed actually retreated westward to the water-parting. The high plateaux that extend along the eastern margin of that divide ought to be striated from west to east or from north-west to south-east. But nothing of the kind occurs. We have no proof whatever to show that the movement of the *mer de glace* in the days of its decline became reversed, so as to flow out from the dominant crests of the land across the tracts in which the seter-terraces occur. On the contrary, glacial striæ, *roches moutonnées*, and the 'carry' of erratics, all alike testify to one movement *from* the old ice-shed across the water-parting. There is not the smallest trace upon the plateaux of any ice-movement in the opposite direction. We are compelled, therefore, to conclude that the ice-shed maintained its position east of the water-parting throughout the whole period of dissolution. The existence of a great Baltic glacier depended, of course, not only upon excessive precipitation but upon a considerable depression of the snow-line. During the maximum extension of that *mer de glace* the snow-line in Southern Norway probably did not rise above a few hundred feet, and it must have been lower still in the central and northern parts of the country. Under such conditions, therefore, it is obvious that the feeding-grounds of the Baltic glacier must have embraced a vast

[1] *Nyt Mag. for Naturvidensk.* Bd. xxxii. p. 258.

region which is now much above the snow-line. During its maximum extension the upper surface of that *mer de glace* at the ice-shed attained a height, according to Hansen, of 6,500 ft. Thus along the ice-shed the depth of ice that covered the elevated moorlands lying to the east of the water-parting was about 3,300 ft., or from 2,600 to 3,300 ft. The ice that streamed across the watershed towards the west was necessarily of inconsiderable thickness. In short, the ice was thickest at the ice-shed and thinned in the direction of the water-parting. When the climate began to change and the snow-line to rise, the movement of the peripheral areas of the Baltic glacier would gradually be arrested. Nor can we doubt that with constant limitation of the snow-fields this change would be developed backwards until the ice in the Baltic basin and over the adjacent low-lying regions became more or less paralysed and inert. With the continued rise of the snow-line ablation would rapidly lower the general surface of the ice-sheet until it finally fell below that line and the ice became throughout an inert mass—or, to borrow Hansen's words, 'en död isklump.' Thus it came to pass that the ice-sheet disappeared first from where it was thinnest, and endured longest where it had attained the greatest thickness—and that, as we have seen, was over the ice-shed.[1]

The dissolution of the last great Baltic glacier was accompanied and followed by the depression of a considerable portion of the Scandinavian peninsula. Communication then obtained between the North Sea and the Baltic by one or more straits across Central Sweden, and there was likewise wide communication between the Baltic and the White Sea by way of Lakes Ladoga and Onega. Denmark, however, was not submerged; on the contrary, there would seem to have been a land-passage from the extreme southern part of Sweden (Scania) across Seeland and the other Danish islands into North Germany. Over the submerged areas were deposited laminated clay, and here and there sand—doubtless both materials being carried down in abundance by the waters escaping from the melting ice which still covered the unsubmerged tracts. Stones scattered through the de-

[1] Hansen, *Om Beliggenheten av Bræskillet, etc.*, p. 73.

ts show further that floating ice played an active part iis time. To the same period are assigned most of the ous 'Strandlinier' of Norway. These are shelves or ıces cut in living rock, at various levels from a few yards ;o 700 ft. and more above the sea. They are in short ıer sea-margins.[1] The upper limits reached by the sea requently distinguished by conspicuous terraces of beach-el and sand, some of which occur at a height of 880 ft. re the present sea-level. The organic remains have a de-dly arctic facies, and consist chiefly of shells and now again of bones of whales and seals. The most cha-eristic shell is *Yoldia arctica*—a high arctic mollusc, ch occurs abundantly in the marine deposits of Western den, and is common in the district of Nerike (Central den). It is met with also in clays in the neighbourhood ıake Mälar. It is noteworthy, however, that in this last-ıed region the shells are somewhat smaller than those of west coast districts—showing that in the Baltic tract water was probably not quite so salt as that of the North [2]

De Geer having taken the levels at which the beaches of old Yoldia Sea occur in Scania, has been led to the con-ion that the upheaval which followed after the depression unequal. Continuing his researches he inserted on a such approximate determinations of the upper marine osits throughout Scandinavia as were available, and nected the various points of equal elevation by lines, ch he terms *isanabases* or *isobases*.[3] These lines showed 'all the points could be grouped in one single system, he higher localities appearing in the central parts of the l, and all the lower ones in the peripheral parts, in the h as well as in the west, the east, and the north, in such ıanner that the isanabases formed concentric circles.'

For references to 'Strandlinier' literature see *Prehistoric Europe*, p. 271. lso L. Holmström's important monograph, 'Om Strandliniens Förskjutning riges Kuster.' *Kongl. Svenska Vetensk.-Akad. Handl.* Bd. xxii. No. 9; Hansen's papers already cited.

H. Munthe, 'Studier öfver Baltiska Hafvets Quartära Historia,' 1892, *ng till K. Sv. Vet.-Akad. Handl.* Bd. xviii. Afd. ii. No. 1; 'De yngsta ena af Jordens Utvecklingshistoria,' *Sommarkurserna i Upsala*, 1893.

Geol. För. Förh. Bd. x. p. 366; Bd. xii. p. 61; *Bull. Geol. Soc. Amer.* ii. p. 65.

He concludes that the old shore-lines indicate continental elevation of the earth's crust.

It is interesting to note that in many of the Swedish lakes there occur certain forms of life which appear to be a relic-fauna of the Yoldia Sea. These are represented by crayfish, seal, &c., of existing arctic marine types.[1]

There is no reason to suppose that the elevation of the land after the late glacial depression was suddenly effected. During the period of greatest depression an arctic flora prevailed in the regions immediately south of the Baltic. The remains of these plants are met with in fresh-water clays underneath the older peat-bogs of Northern Europe. For our knowledge of them we are indebted chiefly to Professor Nathorst,[2] the well-known palæophytologist. They have been discovered in many places over a wide area, as in Norway, Sweden, Denmark, Russia, North Germany, and, as we shall learn afterwards, much farther south. Among the characteristic plants are *Salix polaris*, *Dryas octopetala*, and *Betula nana*, with which various fresh-water shells are occasionally associated. The geographical distribution of these plant-deposits brings vividly before us the conditions that obtained in Northern Europe in late glacial times. We see the low-lying lands that lay beyond reach of the Yoldia Sea dotted with innumerable shallow lakes and lakelets, and clothed with a flora resembling that of the mountains and uplands of Scandinavia and Lapland. While these cold conditions obtained a movement of elevation ensued and the arctic flora migrated into Southern Sweden.[3] This movement continuing, the sea eventually vanished from Central Sweden, the climate became somewhat less severe, and a subarctic flora, comprising, amongst other species, aspens and pines, began to overspread the land.

The submergence indicated by the marine beds of Sweden was not confined to Scandinavia. At Ust-Waga, in the

[1] Lovén, *Öfv. af K. Vet.-Akad. Förh.* 1861, No. 6, p. 285.

[2] Nathorst's earliest discovery of an arctic flora was at Alnarp in Scania, 1870. Since then we have had some twenty papers on the subject from his pen. His last paper (*Bihang till K. Svenska Vet.-Akad. Handl.* Bd. xvii. Af d. iii. No. 5) contains an exhaustive list of references to the literature of the subject.

[3] Gunnar Andersson, *Bihang till K. Svenska Vet.-Akad. Handl.* Bd. xvii. Nos. 2 (1892) and 8 (1893).

ˈy of the Dwina, about 145 miles above Archangel, clays . arctic shells occur overlying the boulder-clay of that ict.[1] And similar deposits are met with in the lower hes of the Petschora Valley, at a height of 300 to 650 ft., re, according to Stuckenberg, they likewise rest upon ground-moraine of that region.[2]

The shelly clays of the Dwina are charged with erratics, cially towards the upper stage of the series; and ice-ed stones and boulders would appear to be common in corresponding shell-beds of the Petschora Valley. It is thy of note here that these shell-beds are overlaid by 1-water deposits which have yielded remains of mammoth reindeer.[3]

We next come to the records of the 'postglacial stage' wedish geologists. On the exposed coast of Estland and arious islands of the Baltic (as Dago, Oesel, Öland, and tland) occur well-marked beaches, containing not a ine but a purely fresh-water fauna. These go up to a ;ht of at least 50 ft. on open coasts, and in the interior r are met with at levels of 100 and 150 ft.[4] It is erally admitted that the fresh-water beaches fringing coasts of those regions up to a height of 50 ft. or so it to the former existence of the Baltic as a great fresh-er lake. These conditions certainly followed after the nigration of aspens and pines, since the beach-deposits rlie the fresh-water beds and peat containing remains of se trees. Finland and the tracts adjacent, which are racterised by an abundance of lakes, would appear in early tglacial times to have been covered even more extensively n now by wide sheets of fresh-water. In many cases the

Barbot de Marny, *Verh. d. russichen k. mineralog. Ges. z. St. Petersburg*, 1868; Schmidt, *Zeitschr. d. deutsch. geol. Ges.* 1884, p. 267.

Bericht über eine geologische Reise in Petschoraland und die Timantundra, . St. Petersburg.

Th. Tschernyscheff, *Rep. Russ. Geol. Com.* Bd. x. p. 95. Tschernyscheff the fauna of the marine shelly clays, &c., resembles that found living round iorth-east coast of the Kola peninsula. He gives 490 ft. as the highest at which he has seen the deposits in the Timan region.

Schmidt, *Zeitschr. d. deutsch. geol. Ges.* 1884, p. 248; Holm, *Bericht geol. Reisen in Estland*, &c. 1883, 1884; H. Munthe, *Öfvers. af Kongl. Akad. Förh.* 1887, p. 719; *Det 14 Skandinaviske Naturforskermöde*, 1892; *markurserna i Upsala*, 1893; also same author's paper on the 'Quaternary ory of the Baltic,' already cited. An outline of the evidence is given in *istoric Europe*, p. 470.

dams that retained these waters were åsar, rendered water-tight by the mantle of loam and clay which often cloaks their slopes. The different levels occupied by the lakes, as their confining barriers successively gave way, are marked by terraces eroded in the sides of the åsar. The fresh-water beaches of the Baltic Lake contain amongst other shells *Ancylus fluviatilis* and *Limnæa ovata*, which are almost invariably present. Certain dark grey clays, covering wide areas in Middle Sweden, are believed to be on the same geological horizon as the Ancylus-beds. It seems probable, indeed, that they form the older or basal series of these lacustrine accumulations. Until recently they were supposed to be almost unfossiliferous, but they have now yielded to the researches of Prof. Nathorst and others an interesting flora and fauna. The plants include *Pinus sylvestris, Alnus glutinosa, Betula verrucosa, B. odorata, Populus tremula, Salix cfr. caprea, Ranunculus repens, Rumex*, sp., *Carex*, sp., *Myriophyllum spicatum*, many mosses, diatoms, &c. The fauna is represented by seal (*Phoca fœtida*), bullhead (*Cottus quadricornis*, var. *relicta*), *Coregonus lavaretus, Bythinia tentaculata, Sphærium corneum, Anodonta cygnea*, insects, ostracods, &c.[1]

Now since it is evident that in early postglacial times the Baltic was a great fresh-water lake, we naturally infer that land-connection must then have obtained between Southern Sweden and Denmark. (Plate XII.) And of this connection there is direct proof, for peat and beach-deposits are met

[1] Nathorst, *Geol. För. i Stockholm Förh.* Bd. xv. p. 539. The fresh-water bullhead is the same as that now living in Lake Vettern, and is believed to be a variety of the marine form which has a wide range northwards, being met with in the Gulf of Bothnia, in the White Sea, and in the Arctic Ocean. The bullhead of Lake Vettern is therefore considered to be a relic of the Arctic Sea, which in late glacial times overflowed South Sweden. Its history, however, is even more complicated. According to De Geer, Lake Vettern was a bay of the Ancylus Lake, and we can hardly doubt that one and the same form of bullhead lived throughout the whole extent of that great sheet of water. It follows, therefore, that the marine form introduced during the preceding glacial epoch (Yoldia Sea) was modified into the Vettern variety after the Baltic area had become lacustrine; and that subsequently, when the Baltic once more obtained connection with the sea, the modified bullhead again reverted to its original form. Dr. H. Munthe has likewise been fortunate enough to detect organic remains in the same 'undre grålera' (lower grey clay). He mentions an ostracod (*Candona candida*), a fresh-water form having a wide distribution in temperate Europe, fish remains, sponge spicules, and fresh-water and brackish-water diatoms. The deposits were certainly accumulated in the great Baltic Lake. *Bull. Geol. Inst. Upsala*, No. 2, vol. i. 1893.

To face page 480 … IC GLACIER Plate XII.

Stanford's Geog.l Estab.t London

ı off the south coast of Sweden at depths of 100 ft. or while river-like channels occur on the bed of the sea in Sound, and the Great and Little Belts, at depths of ft., 230 ft. and 160 ft. respectively, through which it is ›able that the ancient Ancylus Lake discharged its waters. only was the Baltic cut off from the sea, but the southern ; of Sweden would appear to have been 100 ft. higher ı it is at present. It was under these conditions that ɜ and hazels immigrated from the south into Sweden—remains of these trees occurring in peat upon the sea-;om at Falsterbo. From beds of the same age have been obtained many land- and fresh-water shells which le their first appearance in Sweden at this time, along ı urus[2] and bison. The general aspect of flora and ıa is thus suggestive of a temperate climate.

The next succeeding deposits, known as the 'Littorina-s,' bring before us another remarkable geographical nge. The regions of the Kattegat and the southern ion of the Baltic became depressed, until eventually the nd and the Great and Little Belts assumed very much ır present appearance. This movement was experienced r a large part of the Scandinavian peninsula. In Southern eden deposits of the period occur up to 160 ft. at least;[3] the neighbourhood of Hernösand they reach 330 ft. or reabout;[4] in South Norway the highest level attained is ›ut 380 ft. or so.[5]

So far as one can make out, the postglacial beaches and races ascend to higher and higher levels as Central 'eden is approached—thus agreeing in the mode of their tribution with that of the older beaches of the late glacial Yoldia Sea. The deposits of this stage consist not only shelly beach-gravels, but of beds of sand with occasional ›lls, of clay which sometimes contains many plant-nains, of shell-marl, and of silt, with abundant diatoms. e marine molluscan fauna on the Baltic side of Sweden is

E. Erdmann, *Geol. Fören. i Stockholm Förh.* May, 1876.
N. O. Holst, *Ibid.* Bd. x. Häft. 7, 1888.
De Geer, *Bull. Soc. Geol. Am.* vol. iii. p. 67.
Erdmann, *Exposé des Formations quaternaires de la Suède*, p. 91; H. ıthe, *Sommarkurserna i Upsala*, 1893, p. 16.
Kjerulf, *Udsigt over det sydlige Norges Geologi*, p. 3.

poor in species—the common forms being ***Mytilus, Cardium, Tellina, Littorina,*** and *Hydrobia*. In Western Sweden and in Norway, on the other hand, the molluscan fauna is rich in species, owing doubtless to the opener condition of the sea. The Baltic, although not so salt then as the North Sea, was yet sufficiently so to induce the immigration of certain molluscs which are no longer found living in its waters. And it is noteworthy that the Baltic molluscs met with in the Littorina-beds are much larger than their existing descendants. The general aspect of the fauna is decidedly indicative of salter and warmer waters than now lave the coasts of Scandinavia, while the presence of numerous hazel-nuts in the peat of regions which are now beyond the range of that tree shows that the genial conditions of the sea told upon the climate of the land.[1]

Referring for a moment to the glacial succession of Scotland, it will be remembered that in that country a series of relatively small valley-glaciers descended in the Highlands to the sea-coast and dropped their moraines upon the littoral deposits accumulating at the heads of our sea-lochs. We see these moraines now resting upon our raised sea-beaches of the 50-ft. level. This epoch of glaciation must have been experienced also in Scandinavia, and is doubtless represented there by a similar series of moraines; and one is inclined to suspect that the conspicuous terminal moraines which occur at the heads of many Norwegian fiords may be equivalent in time to those of Scotland. I am not aware, however, that any of these moraines have been found resting upon the deposits of the Littorina Sea. Yet there certainly was a stage in the glacial history of Norway when the glaciers were unable to fill the fiords, but just succeeded in reaching or barely reaching the heads of some of those great inlets. When the Baltic glacier reached its maximum extension (fourth glacial epoch) the ice was thick enough to fill the fiords and to advance to the general coast-line of the country. Thereafter followed the retreat of the ice and the appearance of the Yoldia Sea. Next succeeded an epoch of re-elevation and the advent of the great Ancylus Lake,

[1] For an admirable account of the physical geography of the Littorina Sea consult Dr. Munthe's Report, *Bull. Geol. Inst. Upsala*, No. 3, vol. ii. 1894.

accompanied and followed by temperate climatic conditions, during which the land sank again and was overflowed by the waters of the Littorina Sea. Thereafter, judging from the analogy of the Scottish succession, I suspect a renewed advance of glaciers took place—the ice-flows reaching in some cases the heads of the fiords, but being of insufficient thickness to dispossess the sea. Thus, the large terminal moraines that occur in such positions may well be on the same horizon as the valley-moraines of the Scottish Highlands—some of which, as I have mentioned, rest upon the deposits of the 50-ft. beach. During the existence of the great Baltic glacier the ice-shed, it will be remembered, lay considerably to the east of the water-shed—the distance between the two 'divides' being greatest in Northern and Central Scandinavia. In the extreme south of the peninsula they were not so widely separated. It is generally believed that the successive zones of terminal moraines met with in the mountain-valleys of Southern Norway are the moraines of retreat of this latest *mer de glace*; just as, in the same way, the Scottish valley-moraines have hitherto been looked upon as marking successive stages in the retreat of our latest general ice-sheet. I suspect, however, that the successive zones of terminal moraines in these Norwegian valleys may have the same tale to tell as those of Scotland. In our country we have the clearest evidence to show that after the dissolution of our district ice-sheets (=stage of great Baltic Glacier) there ensued another advance of valley-glaciers, the terminal moraines and fluvio-glacial gravels of which rest upon the 50-ft. beach. At a still later epoch a final recrudescence of glacial conditions supervened—now represented by the high-level moraines and corrie-lakes of our loftiest mountain-tracts. Such having been the case in Scotland, one can hardly doubt that a similar succession will eventually be recognised in Norway.

According to Dr. Hansen, however, the terminal moraines occurring at or near the heads of the fiords were accumulated during a pause in the retreat of the last considerable *mer de glace* of Scandinavia—that, namely, which is known as the Great Baltic Glacier. This stage in the retreat of the ice-sheet in question constitutes Hansen's 'epiglacial epoch.'

It must have been a very prolonged pause—the ice-front maintaining its position until the numerous glacier-tongues protruding from it had piled up enormous heaps of morainic débris. The great duration of the epoch is also suggested by the fact that both in south-east and west Norway large valley-lakes are associated with these moraines. Many of the lakes in question are doubtless true rock-basins, and indicative therefore of prolonged erosion; and the contemporaneous terraces and sheets of fluvio-glacial and lacustrine origin, which attain a great development, tell a similar tale. The conditions that obtained in Norway at the time, as Hansen points out, were somewhat similar to those that now characterise Greenland. On Mohn's map of South Greenland, which shows the isotherms for the year,[1] the line of 0° C. runs along the east coast and for some distance up the west coast. Hansen thinks that in like manner the isotherm of 0° C. formerly trended along the south and west coasts of Norway—occupying nearly the same position as the isotherm of 5° C. does at present. In other words, the temperature for the year in Norway was 5° lower in late glacial times than it is to-day. A lowering of the temperature to that extent would depress the snow-line in Southern Norway to the position in which we now find it some 10° farther to the north. This would give an elevation for the snow-line in South Norway of about 2,400 ft. That would correspond fairly well with the snow-line that obtained in Scotland during the existence of the valley-glaciers whose moraines rest upon our 50-ft. beach. The snow-line that characterised the earlier epoch of district ice-sheets in Scotland ranged, as we have seen, between 1,000 and 1,600 or 1,700 ft., and can hardly, therefore, be correlated with that of Hansen's 'epi-glacial epoch.'

Incidental reference has been made to the evidence furnished by the peat-bogs of Scandinavia, which range in age from late glacial down to recent times. Some of these, as we have seen, cover the relics of an arctic flora, while others contain the stools and roots of trees that indicate more genial climatic conditions. It may be well, therefore,

[1] *Petermanns Mitteilungen*, Ergänzungsh. No. 105.

to summarise the evidence yielded by these peat-bogs and their buried forests, and in doing so I shall follow chiefly Professor Blytt, who has for many years made this a special study.[1] In Western Norway the depth of the peat-bogs and the number of alternating layers of peat and root-beds ('forest-beds') increase as we leave the coast and pass inland to higher levels. At the lowest levels the peat is of inconsiderable thickness, and contains only one layer of tree-roots or none at all. At higher levels above the sea two root-beds with two layers of peat are seen in the bogs; while higher still the moors show two root-beds and three layers of peat. The typical succession shown in the moors of the west coast is as follows:—

5. Sphagnaceous peat, about 5 ft.
4. Forest-bed, chiefly of Scots fir.
3. Peat, more compressed than the upper peat, about 5 ft.
2. Forest-bed, with oak-stumps, and often myriads of hazel-nuts.
1. Glacial deposits.

This succession occurs in so many different moors, and with such regularity, that the alternation cannot be assigned to mere local causes. In Eastern Norway Blytt finds that the moors show a more extended succession—four peat-layers alternating with three forest-beds. There, again, as in Western Norway, the depth and number of the layers increase with the height above the sea; but in the oldest or lowest layers oak and hazel are wanting.

In Denmark, as we learn from the researches of Professor Steenstrup, the peat-bogs likewise yield evidence of a succession of wet and dry conditions—root-beds alternating with peat-layers. Resting on the surface of the glacial deposits are fresh-water clays which yield the relics of an arctic flora (*Salix polaris*, *Dryas octopetala*, &c.) Then follows a succession of peat-beds with root-beds—a subglacial flora with *Betula odorata* and *Populus tremula* being met with in and underneath the lowest peat-layer, followed successively by pine-trees (*Pinus sylvestris*), oaks (*Quercus sessiliflora*), and alders (*Alnus glutinosa*). During the oak period that tree was much

[1] Blytt, *Essay on the Immigration of the Norwegian Flora during alternating Rainy and Dry Periods*, 1876; *Engler's Botan. Jahrb.* Bd. ii. 1881; Bd. xvi. 1892; Bd. xvii. 1893; *Förhandl. i Videnskabs-Selskabet i Christiania*, 1882, No. 6; 1892, No. 4; 1893, No. 5.

more plentiful in Denmark than is now the case—the climate being mild and humid. The alder period appears to be co-extensive with the beech period of Danish geologists. Space will not allow me to give in detail the botanical analyses of the various peat-layers of the Danish bogs, but these certainly show, as Steenstrup has pointed out, that the whole series has been accumulated during alternating wet and dry climatic conditions.[1] In the peat-bog of Vidnesdam, for example, we have the same number of climatic changes indicated as in the oldest of the Norwegian bogs. The two lowest of Steenstrup's peat-stages show only high northern and alpine forms—trees that are susceptible to cold are conspicuous by their absence. The oak and the hazel are restricted, as in Norway, to the uppermost stages. Summing up the results obtained by himself and others in Norway, Southern Sweden, and Denmark, Blytt gives the following succession, beginning with the lowest and oldest stage :—

1. *Arctic fresh-water beds* (*Dryas*, *Salix polaris*, *S. reticulata*, *Betula nana*, &c.); severe continental climate.
2. *Subglacial stage*, with *Betula odorata*, *Populus tremula*, *Salices*, &c. The moors wet; climate humid = Danish 'birch or aspen period.'
3. *Subarctic stage*: drier conditions; many bogs become dry and are overspread by forest-growth. The Scots fir (*Pinus sylvestris*) makes its earliest appearance.
4. *Infra-boreal stage*: climate again humid. In Denmark the flora still presents a true northern character; the prevalent forest-tree there being the Scots fir: no trace yet of trees that flourish only under genial conditions = Danish 'pine-tree period.'
5. *Boreal stage*: climate now drier; forests overspread the bogs, forming a 'root-bed.' First indication of a mild climate—the conditions being probably more genial than at present. *Corylus avellana* (hazel) and the oak were more abundant than now. The ash (*Fraxinus excelsior*), and probably also the wild cherry (*Prunus avium*), flourished at this period.
6. *Atlantic stage*: climate mild and humid; the oak (*Quercus sessiliflora*) was more plentiful in Denmark and Southern Sweden than is now the case = Danish 'oak-period.'
7. *Sub-boreal stage*: many of the peat-bogs dry up and are covered by a forest-growth. The oak and the hazel were at this time more widely spread than at present.
8. *Sub-atlantic stage*: the bogs again become wet, and the youngest peat-layer is formed. The 'beech or alder period' of Denmark.
9. *Present stage*: the bogs are drying up and becoming tree-clad.

The stages one to four, it will be remembered, are not

[1] For a more detailed summary of Steenstrup's observations see *Prehistoric Europe*, p. 485. Steenstrup's description of the peat-bogs of Vidnesdam and Lillemose will be found in *K. Dansk. Vidensk.-Selbsk. Afh.* 1841; see further his *Kjökken-Möddinger*, 1886, in which sections of the Danish bogs are given with accompanying explanations and remarks on the succession of forest vegetation since the glacial period.

represented in the peat-bogs that occur at low levels in the coast-lands of Scandinavia. That is because those low-lying tracts were then covered by the sea during the submergence that accompanied the dissolution of the last great Baltic glacier. While the 'subglacial' and 'infra-boreal' peat-layers with the intervening 'subarctic' root-bed were being formed, the land about Christiania-fiord stood some 350 ft. lower than in our day. It was towards the close of the infra-boreal period that the Scots fir spread northwards into Scandinavia. As the climate became milder, oak, hazel, ash, &c., followed—the 'boreal period' of Blytt corresponding to the lacustrine stage in the history of the Baltic. The 'Atlantic stage' of Blytt's succession coincided with the so-called 'postglacial depression,' which was marked by the formation of the Littorina-beds. The 'sub-boreal' dry period, again, concurred with the retreat of the postglacial sea from the low grounds of Scandinavia, while the 'subatlantic peat' was formed during the last stages of that retreat.[1]

Blytt's observations on the peat-bogs of Norway are closely paralleled by those of Herr Sernander in the moors of Sweden. Thus the latter finds that the oldest Swedish peat-bogs contain four peat- and three root-beds, which show the same succession of conditions as in Norway. We have seen also how closely the results obtained by Steenstrup agree. In many other parts of Northern Europe a succession of 'forest-beds' has been met with, as in Estland, in Gottland, and in Finland, and we cannot doubt that the vast area over which such phenomena are exhibited points to other than mere local changes. The time will come when it will be

[1] Mr. R. Hult, from a study of the moss-flora of the tracts between Aavasaksa and Pallastunturit in Finland, finds evidence of the following succession of climatic changes:—

1. *The arctic period*: with cold climate and an arctic flora in the low grounds.
2. *The sub-arctic period*: with a cool and perhaps somewhat dry climate, like that of the northern forest-regions of the European coast-lands.
3. *The southern period*: with warm climate, like that which now obtains in the oak-region of Scandinavia; no indications of great dryness.
4. *The maritime period*: with a strongly-marked 'sea-climate,' somewhat cooler than that which now prevails in the same region.
5. *The present period*: drier and possibly somewhat warmer than the immediately preceding period—a strongly-marked continental climate.

('Mossfloran i trakterna mellan Aavasaksa och Pallastunturit,' &c., *Acta Societatis pro Fauna et Flora Fennica*, t. iii. No. 1, p. 66, 1886.)

possible to correlate the various 'forest-beds' of all those separate tracts, and thus trace out in detail the various modifications and changes which have affected the flora of Northern Europe since the disappearance of the last great Baltic glacier.

Professor Blytt has recently studied the calcareous tufas of Norway, which have yielded many plant-remains, that enable the deposits to be correlated with the peat-bogs.[1] He finds a succession of such tufas alternating with loams, &c., which seems to him to indicate alternating wet and relatively dry conditions. Thus in Gudbrandsdal the following section is seen at Leine, about 2,000 ft. above the sea :

Humus, 4 to 6 inches.
Greyish white tufa, with abundant 'needles' of Scots fir, occasional cones, and some bark ; 22 to 26 inches.
Greenish-grey loam, not calcified, less than an inch.
Yellow-grey tufa, rather earthy ; less than an inch ; with abundant leaves of *Dryas octopetala*, also remains of *Betula nana*, *Salix reticulata*, &c. Some pine-needles occur, but not so abundantly as in the upper white tufa, and they are also shorter and narrower.
Yellow-grey, laminated tufa, 18 inches, with abundant remains of birch (*Betula odorata*), aspen, willows (*Salix caprea*, *S. glauca*), and grey alder (*Alnus incana*), but no trace of Scots fir.
Ferruginous loam, not calcified.
Boulder-clay.

Blytt's reading of this section is shortly as follows :—First we have a time of great precipitation, and a glacier occupies the upper reaches (at least) of Gudbrandsdal. The glacier next vanishes, and we meet with the earliest traces of a dry period, during which no calc-tufa was formed, but a ferruginous loam was deposited. By-and-by, however, springs become very active, and tufa forms plentifully, while the hill-slopes are clothed luxuriantly with birches, aspens, and willows. As yet, however, no Scots fir appears, nor is there any trace of leafy trees that cannot stand a cold climate. Thereafter follows a dry period, during which the springs are not active, and little or no tufa is formed. *Dryas* and other arctic plants flourish on what appears to have been the upper margin of the pine-forests of the district. Soon the springs dry up, and the greenish-grey loam is deposited. Again, however, the rain-fall increases, and tufa-forming springs once more become very active. But this time they gush forth not in a bright green

[1] *Engler's Botan. Jahrb.* Bd. xvi. Heft 2, No. 36, 1892.

ı-wood but in the gloomy shade of a pine-forest. And in our own day the springs are again dried up, and the Picea Abies), of which not a trace occurs in the tufas, become a native of the neighbourhood. At a lower level ft. above sea) in the same region another section of -deposits occurs, which tells the same tale of alternating and dry conditions. Here (at Nedre Dal) as at Leine thick beds of tufa occur—each of which contains the e assemblage of species in the same order. Owing to low level of Nedre Dal, however, the arctic forms do not ear.

Similar tufa formations are known to occur in other s of Scandinavia, which in the light of Blytt's researches deserving of a more detailed examination than they have received. That tufa is no longer in our day forming to same extent in the same places appears certainly to be of these Scandinavian accumulations. According to Sernander, the tufa of Nässet in Jemtland must have been osited not only under other conditions of drainage, but er quite a different kind of climate.[1] And Nathorst, iking of Swedish Norrland, remarks that nowadays the nation of calc-tufa in that region is hardly worth consing, it is so meagre.[2] It would seem also that the Picea Abies) has never yet been met with in any of the -tufas in Scandinavia—it is clearly a later comer than Scots fir.

The observations recorded by Blytt are so interesting, have so obvious a bearing on late glacial and post-cial history, that they must induce a study of similar cal-eous accumulations in other countries. Already, indeed, Fliche has drawn attention to certain calcareous tufas peat-beds occurring at Lasnez, near Nancy, in which he ognises an alternation of beds similar to that described Blytt. The tufas, he says, alternate with vegetable soils, ing the formation of which the climate was drier than en the tufas were being accumulated.[3]

No relics of Palæolithic man have been detected any-

Botanisches Centralblatt, 1891, No. 40.
Geol. Fören. i Stockholm Förh. Bd. vii. p. 762; *Föredrag i botanik vid et.-Akad. högtidsdag den* 31 *Mars*, 1887.
Bull. de la Soc. des Sciences, etc. de Nancy, 1889.

where in Northern Europe in beds of later date than the accumulations of the third glacial epoch. Implements, &c., of Neolithic age, on the other hand, make their first appearance on a much higher horizon. They occur in the older beds of peat, but never in the clays with arctic plants which underlie the peat-bogs. It would seem, then, that Neolithic man did not appear in Northern Europe until the cold of the fourth glacial epoch was passing away.

Before we turn our attention to the glacial history of other parts of Europe, I may indicate here some of the chief results at which we have arrived. It will be observed, then, that we have evidence to show that the low-grounds of north-western Europe have been invaded on three occasions at least by great *mers de glace*. The ground-moraines of the earliest of these three successive ice-sheets we recognise in the so-called 'lower boulder-clay' of Britain, of Middle and Southern Germany, and of Central Russia. The next is represented by the 'upper boulder-clay' of Britain and the continental regions just named, and by the so-called 'lower boulder-clay' of the Baltic coast-lands. The accumulations of the third of the series we see in the 'upper boulder-clay' and the great terminal moraines of the Baltic area, and in the district boulder-clays and large valley-moraines of Britain and Ireland.

Between the two older ground-moraines as thus defined occur interglacial accumulations which show that after the disappearance of the earliest and greatest of the three *mers de glace* a wide land-surface with genial climatic conditions obtained in Northern and North-western Europe. The advent of the second and lesser ice-sheet was heralded and accompanied by submergence which in the British area exceeded 500 ft. below the present sea-level. The dissolution of this second *mer de glace* was, as before, succeeded by wider land-surface and temperate conditions. Thereafter followed renewed submergence, to a depth in Scotland of 130 ft. or thereabout. Contemporaneously with this depression district ice-sheets and large valley-glaciers appeared in the British area. Similarly in Northern Europe a great Baltic glacier came into existence, the retreat of which was

ccompanied by considerable submergence in Scandinavia nd Northern Russia.

I have further given the evidence adduced by Nathorst nd others to show that the earliest of the three *mers de glace* eferred to above was preceded by a yet older ice-sheet—by great Baltic glacier, which I infer was synchronous with he appearance of an arctic fauna in the North Sea (Weyourn Crag). In short, the evidence leads to the concluion that the Glacial Period commenced in Pliocene times— conclusion which, as we shall afterwards see, is borne out y what is known of the glacial succession in Central and Southern Europe.

Finally, we have learned that subsequent to the dissolution of the last great Baltic glacier and the district ice-sheets of the British area a genial climate supervened. In the earlier stages of this epoch the Baltic existed as a fresh-water ake, and the British area was continental. Great forests hen overspread North-western Europe. Eventually submergence ensued in Scandinavia and Britain—in the former ountry to the extent of 380 ft., while in Scotland it did not exceed 50 ft. or thereabout. When this depression had eached its climax, glacial conditions again supervened— onsiderable glaciers occupying many of the mountainvalleys of the British Islands, and here and there in the Scottish Highlands descending to the sea-level. Valleyglaciers must have existed in the mountain-valleys of Norway at the same time: but we do not yet know what relation the valley-moraines of that region bear to the accumulations of the Littorina Sea.

In the higher mountain-tracts of Scotland there occurs yet another set of moraines and glacial lakes, which point o a distinct re-advance of the glaciers in what is usually onsidered to be the postglacial period. This final appearance of permanent snow-fields in Scotland is to be correlated, I believe, with the later raised beaches of that country. The epoch of submergence represented by the older raised beaches (50-ft. level) was succeeded by re-emergence of the land and the recrudescence of forest-growth. The British area was more extensive then than now, but we have no evidence to show that it became again united to

the Continent. To this stage of land-elevation succeeded renewed depression, with a relapse to cold and humid conditions, when the forest-growth was largely arrested and peat-bogs greatly increased. It was during this last epoch of submergence that the final recrudescence of glacial conditions probably took place, and permanent snow-fields and glaciers appeared in the most elevated tracts of the Scottish Highlands. With the subsequent re-elevation of the land to its present level the Scottish snow-fields finally vanished and existing conditions ensued.

If I am asked where we should draw the line between glacial and postglacial times, I say that much depends upon how we look at the matter. If the Scottish succession be taken as a type, then it would follow that the Glacial Period closed with the final disappearance of our snow-fields. But if the existing snow-fields and glaciers of Europe be looked upon as surviving relics of earlier times, then we might say that we are still living in the Glacial Period. We have seen that, after the climax of cold had been passed, each successive glacial epoch declined in importance—the latest cold phase in Scotland being marked by a snow-line at 3,500 ft. With the disappearance of our latest glaciers the long cycle of climatic alternations appears to have terminated. I think, therefore, that if we are to retain the term 'Glacial Period' for that cycle, it must include the latest phase of local glaciers in Britain. To separate the later stages from the earlier, and to designate them as 'postglacial,' only tends to confusion. This will appear obvious enough when we have ascertained the character of the glacial succession in the Alpine Lands. If we adopt the views of Swiss geologists, and apply the term 'postglacial' to the several phases that succeeded their third glacial epoch, then we shall be compelled to include the last great Baltic glacier and the district ice-sheets of Britain, along with our arctic shelly clays, in the postglacial period! So long as the term is used with only a local application it has a certain convenience. But the postglacial deposits of one region are not necessarily synchronous with the accumulations so designated in other countries. Some geologists in England, for example, still speak of the Palæolithic gravels

of the Thames as 'postglacial,' when all that they actually mean is that these gravels are younger than the great chalky boulder-clay. It will be seen, therefore, that such use of the term does not make for clearness, and has in point of fact led to considerable confusion. Until geologists are agreed as to the particular stage at which the climatic alternations of the Pleistocene finally terminated, it would be much better to avoid the use of the word altogether.

CHAPTER XXXII.

GLACIAL PHENOMENA OF THE MOUNTAINS OF MIDDLE EUROPE.

The great Timan Glacier—Glaciation of the Urals—Old glaciers of the High Tatra; of the Owl Mountains, the Riesen-Gebirge, the Erz-Gebirge, Frankenwald, Vogtland, and the Harz—Glacial phenomena of the Black Forest and the Vosges—Diluvial deposits of the Swabian Jura—Distribution of cirques in the mountains of Middle Europe—Correlation of the glacial deposits of Middle and Northern Europe.

THE presence in the low-grounds of Central Russia and Germany of a vast *mer de glace* implies conditions of climate which could not fail to affect the mountainous tracts lying just beyond the margin of the great inland ice. We are not surprised to learn, therefore, that the Urals in the far east, and the various mountain-ranges that straggle across Central Europe from east to west, have yielded more or less abundant traces of the former existence of snow-fields and glaciers. Reference has already been made to the fact that the Timan Heights in the north-east of Russia seem to have formed an ice-shed, separating the Scandinavian *mer de glace* from the very much smaller, but still extensive, ice-sheet that occupied the basin of the Petschora. This latter appears to have been derived partly from the Timan Heights and partly from the Urals. At the same time a broad sheet of ice descended the opposite slopes of the Ural Mountains into the valley of the Obi.[1] We may picture to ourselves, therefore, the whole range of the Urals, extending between lat. 62° and the Arctic coast-lands, as covered with wide snow-fields, from which continuous ice streamed outwards on both sides into the adjacent low grounds. South of lat. 62° the snow-fields of the Urals nourished only local glaciers. Thus, in lat. 61° their moraines have been observed by

[1] S. Nikitin, *Petermanns Mitteilungen*, 1886, p. 257.

edoroff.[1] Glacial phenomena have also been recorded .. Poliakoff as far south as Ekaterinburg.[2] It is worthy te that although the Urals, in their northern extension, ı an elevation of 4,000 to 5,000 ft. at least, they yet ›t now reach the snow-line, and of course support no ers. This is the more striking when we remember that e same latitudes in Norway the snow-line occurs at a ıt of only 2,300 ft.

/e turn our attention now to the mountains of Central pe, which we shall follow from east to west. Beginning the Carpathians, we find that hitherto few traces of ıl action have been met with in the southern and rn sections of that chain. Rock striæ, *roches moutonnées*, ics, and moraines, however, have been observed by Herr nann in the Fogaras Mountains (Transylvanian Alps) at ght of 1,950 metres. MM. Tietze and Paul have also vered moraines on the northern slopes of the Hoverla, the head waters of the Pruth (East Carpathians).[3] e, they tell us, indicate the former presence of a small er which descended from the mountain-ridge to the level 360 metres (4,462 ft.) above the sea. In the Central athians, however, glacial phenomena are more abun- y developed. According to Professor Partsch,[4] glaciers erly occupied all the valleys radiating from the High ı—that section of the mountain-chain which extends een the Kopa Pass (1,773 metres) in the east, and the czkowa Pass (1,805 metres) in the west. The ridge of Iigh Tatra is some fifteen miles in length and has an ge elevation of 7,500 ft. In this region *roches mouton-* glacial striæ, lateral and terminal moraines, and other nce of ice-action are everywhere conspicuous. From dmirable researches of Professor Partsch we learn that al of the glaciers attained very respectable dimensions. the glacier of Javorina, fed from five high valleys, d north for $6\frac{1}{2}$ miles. At the point where the last of ibutaries joined it the united ice-flow was 330 ft. thick

[1] *leues Jahrb. für Min.* &c. 1888, Bd. i. p. 173; 1891, Bd. i. p. 316.
[2] *lature*, 1877, p. 306.
[3] *'erh. der k. k. geolog. Reichsanst.* 1876, p. 296; *Jahrb. der k. k. geolog. anst.* 1877, p. 87; 1886, p. 690.
[4] *ie Gletscher der Vorzeit*, &c. 1882.

and 760 to 870 yards broad. At its lower end the glacier had a width of 1,300 yards and a thickness of at least 230 ft.—its terminal moraine having a height above the valley-bottom of 220 ft. This moraine lies at an elevation of little more than 3,000 ft. above the sea. Many other ice-streams descended the northern slopes, some of them rivalling the Javorina glacier. The glaciers developed on the south side of the mountain-ridge were also relatively large. Thus the glacier of the Kolbach Valley was over 1,000 yards broad and some 500 ft. thick. Another, that of the Popper Valley, descended to the level of 3,300 ft. above the sea, after a course of five miles.

More recently the High Tatra has been visited by Dr. A. Rehmann, who adduces evidence to show that the terminal moraines described by Dr. A. Partsch do not indicate the utmost limits reached by the glaciers. He thinks that the glacier of the Bialka Valley may have been twenty miles in length. His descriptions, indeed, suggest that the old moraines of the Tatra do not all belong to one and the same stage of glaciation. Wide sheets of coarse angular gravels which spread out over the low grounds at the foot of the mountains are probably, in his opinion, the relics of an earlier glaciation—resembling as they do the cemented 'diluvial' gravels at the base of the Alps, the fluvio-glacial origin of which is not doubted.[1]

The chain of mountain groups and ridges, known under the general name of the Sudetes, which extends along the borders of Austria and Germany, has yielded similar satisfactory evidence. According to Partsch, no unequivocal traces of glaciation are met with in the mountains that form the south-eastern portion of the chain, namely, the Altvater-Gebirge and the Schneeberg. They occur, however, in the Owl Mountains (Eulen-Gebirge), which extend between the valley of the Neisse and Waldenburg. Here Herr Stapff detected ground-moraines, lateral moraines, *roches moutonnées* and glacial striæ.[2] The glacier, indicated by these traces, descended from a height of 700 metres (2,297 ft.) to the level of 400 metres (1,312 ft.) above the sea, and Stapff justly infe

[1] *Mitth. d. k. k. geogr. Ges.* 1893, 8 u. 9.

[2] *Jahrb. d. königl. preuss. geol. Landesanst. für* 1888, p. 105.

rom this that glaciers must at the same time have existed n other valleys of this mountain-range, the culminating idge of which exceeds 1,090 metres in elevation.

It is amongst the groups and ridges that form the northern ortion of the Sudetic chain, however, that glacial phenomena ppear most conspicuously. The glacial phenomena of the Riesen-Gebirge were studied by Professor Partsch a number f years ago,[1] and he has recently re-investigated the region nd obtained a rich harvest of results.[2] The culminating eights of the mountains are between 4,800 ft. and 5,200 ft., nd are drained by numerous streams, some of which flow outh into the Elbe, while others make their way north to he Bober. Most of the high valleys contain well-marked erminal and lateral moraines, which are clearly the relics of t least two separate epochs of glaciation. The evidence, ndeed, seems strongly to suggest that there were even three uch epochs. Not only do moraines occur at three successive tages, but each belt of moraines is accompanied by its fluvio-glacial terrace—in the same manner as the corresponding morainic ridges of the Alpine 'Vorland' are associated with uccessive sheets of gravels. According to Partsch, the snow-ine at the epoch of maximum glaciation had an average elevation of about 1,200 metres (3,937 ft.)—occurring at a ower level on the northern than on the southern slopes of he range. The entire snow-field covered an area of 84 square kilometres, and fed some fifteen glaciers at least, which varied in length from a little less than one mile up to rather more than three miles. One of the largest—the Aupa glacier—exceeded 300 ft. in thickness. The terminal moraines of these glaciers, which belong to the earliest glacial stage, occur at heights of 2,600 ft. up to 2,950 ft. The moraines of the next succeeding series of glaciers do not appear below heights of 3,200 ft. to 3,600 ft. On the north-ern slope of the western section of the mountains the several successive stages of moraines are particularly well-developed. The Kleine and the Grosse Grube are two cirque-like depres-sions on the flanks of the Veilchen Koppe (4,826 ft.) and the Hohes Rad (4,937 ft.). The flat bottom of the Grosse

[1] *Die Gletscher der Vorzeit, &c.* 1882.
[2] *Die Vergletscherung des Riesengebirges zur Eiszeit*, Stuttgart, 1894.

Grube (4,177 ft.) is margined by a crescent-shaped morainic ridge, about forty feet high, composed of angular blocks and débris. Some 300 yards in advance of this moraine occurs another similarly-shaped mound, nearly 150 ft. in height—obviously the terminal moraine of a glacier flowing from the Grosse Grube. Further down the slope a much larger ridge of blocks extends across the declivity in front of both the Kleine and the Grosse Grube. This moraine occurs at a height of 3,796 ft., and marks the limits reached by a glacier which was obviously fed from the névé of the two corrie-like depressions. Lower down still, at an elevation of 3,150 ft., we encounter the large moraines of the outer zone—those, namely, which were heaped up during the maximum glaciation of the Riesen-Gebirge. It is particularly noteworthy that these moraines, although they date to one and the same epoch, are the products of two separate glaciers. At the time of their formation the rock-divide which separated the Kleine from the Grosse Grube must have been so strongly pronounced that the ice-flows streaming from the two corrie-like basins were unable to coalesce, and flowed throughout their entire course, from source to termination, as single independent glaciers. Subsequently they melted away, and a long epoch of erosion and denudation supervened, during which the rock-divide separating the adjacent Gruben was so reduced, that when the next glacial epoch succeeded, the ice streaming from the two basins readily became confluent. They thus formed one broad ice-mass, in front of which a single continuous moraine was deposited.

The fluvio-glacial gravels of the Riesen-Gebirge bear similar testimony to the periodicity of glaciation. In the following chapter some account of the gravel-terraces of the Alpine valleys will be given. It will be shown that these gravels were deposited during successive epochs of glaciation—each such epoch being followed by a more or less prolonged stage of valley-erosion. Professor Penck was the first to point this out in a clear and convincing manner, and his interpretation of the facts applies equally well, as Professor Partsch shows, to the similar phenomena encountered in the valleys of the Riesen-Gebirge. In that region fluvio-glacial gravels occur on three separate horizons. First come the

sheet-gravels' (Deckenschotter) which were spread over the ld land-surface before the existing valleys had been eroded › their present depths. They thus extend over the ground ring between separate valleys. Next follow in succession ıe 'high-level' and 'low-level' terraces, both of which occur ithin the valleys. The interpretation of these facts is ıortly as follows: The deposition of the 'sheet-gravels' as succeeded by an epoch of erosion when streams and vers cut their way down through the superficial accumulaons in question into the solid rock. In other words the rainage of the mountains was concentrated along certain nes, and the lower reaches of the valleys were thus excaated. Then followed the epoch of maximum glaciation—hen glaciers descended the mountain-valleys and immense uantities of coarse shingle and gravel were swept downwards, o as to largely fill up the previously excavated lower reaches. Eventually those glaciers retreated, and river-erosion recomnenced—the waters working down through the thick masses of fluvio-glacial gravels. Thus in time these gravels came o form high terraces flanking the sides of the valleys and overlooking the broad trenches of river-erosion. Next ensued another epoch of glaciation, not so excessive as the first, and a new series of fluvio-glacial gravels was accumulated at a ower level between the high terraces of the preceding epoch. Again the glaciers retired—excessive accumulation ceased, and was succeeded as before by a long-continued epoch of valley-erosion—the streams cutting down through the lowevel terraces into the subjacent solid rock.

According to Professor Partsch, none of the glaciers of the Riesen-Gebirge exceeded three miles or so in length. Professor Berendt, however, thinks he has obtained evidence of a much more extensive glaciation.[1] He is of opinion that the broad depression of Schreiberhau, lying between the Hohe Isar Kamm and the Riesen-Gebirge was formerly occupied by a gigantic glacier. He bases this conclusion chiefly on the abundant occurrence of 'giants' kettles' and 'pot-holes' (Gletschertöpfe and Strudellöcher). These are of such a character and appear in such positions as to

[1] 'Spuren einer Vergletscherung des Riesengebirges,' *Jahrb. d. königl. preuss. geol. Landesanst. für* 1891 (1892); *ibid. für* 1893 (1894), p. 22.

show, he thinks, that they have been formed by *moulins* or glacier mills. Professor Partsch, on the other hand, points out that the curious pits and hollows referred to by Berendt have not the characteristics of the 'giants' kettles' of glaciated regions. Moreover, they occur not only in the solid ground-rock, but likewise in blocks that are scattered over the surface. Still more suspicious is the fact that the pot-holes are practically confined to granite—only one example occurs in gneiss, while they are entirely wanting in all the other rocks of the Riesen-Gebirge. Partsch concludes that they are the result of the superficial weathering of the granitoid rocks, and have nothing to do with glacial action.

The great Scandinavian inland ice reached the foot of the Riesen-Gebirge, and seems to have had some influence in modifying the drainage of those mountains. Dr. Schottky's observations in the lower reaches of the Hirschberg Valley, which opens directly into the valley of the Bober, seem to show that the muddy water descending from the Riesen-Gebirge was to some extent dammed back by the Scandinavian ice. Hence one or more lakes came into existence and formed receptacles for the silt and mud brought down from the mountains.[1]

The Erz-Gebirge, according to Professor Partsch, would seem not to have supported even local glaciers; but more recently distinct traces of these have been discovered by MM. Sauer and Laube.[2] More remarkable than these are the ground-moraines which E. Dathe describes as occurring in the Frankenwald and the high grounds of Vogtland.[3] These mountains are more or less isolated and attain no greater elevation than 2,500 ft. and 2,000 ft. respectively; and yet the presence of the boulder-clays with their scratched stones, and the absence of superficial morainic débris, seem to show that the high grounds in question have been mantled with ice-sheets. His interpretation of the evidence, however, has been called in question.[4] It does not seem at all probable

[1] *Beiträge zur Kenntniss der Diluvial-Ablagerungen des Hirschberger Thales*, 1885.

[2] *Erläut. z. geolog. Specialk. v. Sachsen, Sect. Kupferberg*, Blatt 148, p. 80; C. Laube, *Verhandl. d. k. k. geol. Reichsanst.* 1884, p. 194.

[3] *Jahrb. d. königl. preuss. geolog. Landesanst. für* 1881, p. 317.

[4] A. Penck, *Ausland*, 1884, p. 644.

hat elevations so inconsiderable should have been wrapped in an ice-sheet, while only local glaciers existed in loftier ranges occurring in the same latitude.

The Harz Mountains (3,600 ft.) also appear to have had their snow-fields and glaciers, the moraines of which have been noted by K. H. Zimmermann, E. Kayser, and others.[1]

The Black Forest, owing doubtless to its proximity to the great glacial region of the Alps, was early visited by inquisitive glacialists. In 1841 Agassiz detected moraines in the northern part of the range; but, as Professor Partsch remarks, the first impulse to the study of the old glaciers of the Black Forest came from the late Sir A. C. Ramsay, who gave a clear description of the moraines in certain valleys that radiate from the Feldberg.[2] He was followed fourteen years later by M. Gilliéron, who studied in detail the glacial phenomena exhibited in the valley of the Wiese;[3] and by Herr Platz, who gave a short sketch of similar appearances.[4] The observations of these geologists appear to have been confined to the highest part of the range—to the region immediately surrounding the Feldberg, which is the dominating point (1,495 metres) in the southern section of the Black Forest. More recently we have from Professor Partsch a general description

[1] Zimmermann, *Neues Jahrb. f. Min. Geol. u. Pal.* 1868, p. 155; Kayser, *Verh. d. Ges. für Erdkunde zu Berlin*, 1881, Bd. viii. p. 245. See also K. A. Lossen, *Zeitschr. d. deutsch. geol. Ges.* 1881, Bd. xxxiii. p. 708. By some geologists the evidence adduced is considered unsatisfactory; see O. Lang, *Neues Jahrb. für Mineralogie*, &c., 1880, Bd. ii. p. 99; K. A. Lossen and F. Wahnschaffe, *Jahrb. d. k. preuss. geol. Landesanst. für* 1880, p. 124. Franz Bayberger thought he had discovered evidence to show that the Bohemian Forest formerly supported glaciers (*Petermanns Mitteilungen*, Ergänzungsheft, No. 81), but Messrs. Penck, Böhm, and Rodler could find no trace of moraines, erratics, or striated rocks in any of the valleys (*Zeitschr. d. deutsch. geol. Ges.* 1887, p. 68). Several lakes, however, occur at considerable elevations, some of which at all events lie in rock-basins. The Kleine Arber See (3,015 ft.) appeared to Professor Partsch to be a moraine-dammed lake, and the valley-bottom immediately below the lake had all the aspect of a 'Moränenlandschaft.' He noted two converging side-moraines, one thickly wooded, the other composed of blocks and forming a ridge some 30 ft. in height. The bottom of the valley was paved with a thick accumulation of blocks set in a loamy matrix, which he took for a ground-moraine; but he does not mention the occurrence of glacial striæ. (*Die Gletscher der Vorzeit*, p. 110.) As the mountains of that region rise to heights of 4,560 to 4,680 ft. it is probable that they were snow-clad and sustained glaciers, but further observation is needed to make this quite certain.

[2] *Quart. Journ. Geol. Soc.* 1862, p. 185.

[3] *Archives d. Sciences phys. et nat.* 1876, p. 136.

[4] *Neues Jahrb. für Min.* &c. 1878, p. 56; and a later paper by the same author, *Zeitschr. d. deutsch. geol. Ges.* Bd. xlii. 1890, p. 595.

of the glacial phenomena of the whole of this region, which it need hardly be said has considerably increased our knowledge.

There can be no doubt now that the glaciers descending towards the Rhine Valley were more or less coalescent. Indeed, there is reason to believe that the glaciers of the Black Forest became confluent in the south with the colossal ice-streams of Switzerland.

The upper valleys in the northern part of the Black Forest have apparently not been critically examined, and we do not know, therefore, whether they contain moraines. But, according to Professor O. Fraas, the whole of that region must have been glaciated. In the valley of the Nagold, a tributary of the Ens, both of which rise on the north-east slopes of the Black Forest, he has detected what he believes to be undoubted morainic accumulations at a height of 330 metres above sea-level. Again in the valley of the Ens, near Wildbad, numerous colossal erratics are scattered over hill-tops and hill-slopes; while at Calmbach (392 metres) he found smoothed and striated boulders. If these be really of glacial origin, the Black Forest must have been swathed in its own ice-sheet—the valley-glaciers becoming confluent in their lower reaches.

The recent observations of Professor Steinmann in the southern section of the Black Forest tend to similar conclusions. He describes broad sheets of morainic materials as sweeping out from the mountains down to the margin of the Rhine flats. Neither in composition nor structure can these accumulations be confounded with the products of subaerial action, while the great distances to which they extend from the steep slopes of the hills prove, he says, that they are not comparable to the sheets of débris that gather in mountain-regions. These last are usually more or less loosely piled up and show traces of rude bedding; but the morainic deposits in question are confused unstratified masses of different kinds of rock-fragments—the accumulations showing more or less strong evidence of having been sub ected to some kneading process. No scratched stones seem to occur; but, as Steinmann remarks, were the Schönberg, near Freiburg, which is built up of chalk, marl, and clay, to be covered by inland ice, the ground-moraine of the latter could hardly

iffer in character from that of the structureless mass referred ɔ, and, like it, would contain no striated stones. He further raws attention to the very general appearance in the region nder review of 'terminal curvature,' [1] and superficial disloca-ion of the stratified rocks. The outcrops for a few yards :om the surface are bent over, folded, or crushed. Hori-ɔntal or gently inclined strata are often doubled up or over-ɔlded, or crumpled and contorted—the horizontal displace-ɪents exceeding two yards in extent. The folding is most onspicuous among the more yielding strata, the harder beds ɪterstratified with these being crushed and shattered, and heir fragments separated and inclosed in clay which has een squeezed between them. All the appearances show hat the rocks have been subjected superficially to tangential ɔush and thrust. Sometimes the disturbed rocks are buried ınder thick morainic materials; in other places only sporadic ɜrratic blocks and rounded stones are scattered over the surface, or the rocks may show no covering of any kind. Professor Steinmann has met with these disturbed rocks at all levels, from the heights of the Black Forest down to the flats of the Rhine, not only in the Baden Oberland, but also in other parts of the Rhine valley. He is of opinion, there-fore, that the whole region at the climax of glacial conditions was covered with ice.[2]

The same author recognises two ground-moraines in the larger valleys that descend from the Black Forest (as in the Wehrathal), each of which is associated with a well-marked ;errace of fluvio-glacial gravel. In company with Dr. Du Pasquier he has worked out the connection of these moraines and terraces with the similar accumulations in North Switzerland, and has shown that the two series are identical. The low-level terraces of southern Baden and North Switzerland are directly associated with the so-called

[1] See *ante*, p. 396.

[2] I do not willingly venture to call in question the soundness of Professor Steinmann's conclusion, but I am not satisfied that all the accumulations lescribed by him are of true morainic origin. Some of the 'drifts' which :loak the hill-slopes of the Black Forest seemed to me, when I visited that region some years ago, to resemble greatly the 'rubble-drifts' of southern England and other regions, and may possibly, therefore, have been formed, as these are supposed to have been, rather by the action of 'frost and thaw' than by true glacier-ice.

'inner moraines' at the foot of the Alps. The high-level terraces, on the other hand, are in immediate connection with the moraines of the outer zone, and pertain to the epoch of maximum glaciation.[1]

Finally, Dr. Steinmann points out that the terminal moraines in the higher valleys of the Black Forest belong to a later stage than the low-level gravel-terraces and moraines of the inner zone. He correlates them, in short, with the so-called 'postglacial moraines' of Switzerland, which fall to be described later on.

Crossing the Rhine we come next to the Vosges—a range of mountains in the valleys of which glacial phenomena are well developed. These appear to have been first noticed by two French geologists—MM. Le Blanc[2] (1837) and Renoir,[3] (1839); but immediately afterwards appeared the classical works of Hogard,[4] and the no less admirable descriptions of Collomb.[5] Thanks to the researches of these pioneers and to the later observations of Grad,[6] Gerland,[7] Schumacher,[8] and others, the glacial phenomena of the Vosges are hardly less well-known than those of Switzerland. Rock-striæ,

[1] *Zeitschr. d. deutsch. geol. Ges.* Bd. xliv. (1892), p. 541; *Bericht über die XXV. Versammlung des Oberrheinischen geolog. Vereins zu Basel; Mitt. d. Grossh. Badischen geolog. Landesanstalt,* Bd. ii. p. 395. More recently Professor Steinmann has detected another terrace, intermediate in age between the high-level and the low-level terraces. This 'middle terrace' would appear to pertain to the same general horizon as the high-level terrace—the two together being equivalent to the 'moraines of the outer zone.' See 'Ueber die Gliederung des Pleistocän im Badischen Oberlande,' *Mitt. d. Grossh. Badischen geolog. Landes-anst.* Bd. ii. (1893) p. 746.

[2] *Bull. de la Soc. géol. de France,* t. x. p. 377; t. xii. p. 132.

[3] *Op. cit.* t. xi. p. 53; *Edin. New Phil. Journ.*, vol. xxix. (1840) p. 280.

[4] *Annales de la Soc. d'Emulation du Dép. d. Vosges* (Épinal), 1840, p. 91; 1842, p. 524; *Coup d'œil sur le Terrain erratique des Vosges,* 1851; *Bull. de la Soc. géol. de France,* 2e Sér. t. ii. (1845) p. 249.

[5] *Bull. Soc. géol. de France,* 2e Sér. t. ii. (1844-45) p. 506; t. iii. (1845–46) p. 180; t. iv. (1846-47) pp. 216, 580, 1156; t. vi. (1848-49) p. 479; t. ix. (1851-52) p. 89; *Bibliothèque universelle des Sciences, etc., Genève,* t. lx. (1845) p. 156; *Supplément à la Bibl. Univ. et Revue Suisse* (*Archives d. Sci. phys. et nat.*), t. i. (1846) p. 259; t. vi. (1847) p. 199; *Revue scientifique,* t. i. (1848) p. 47; *Mémoires de la Soc. du Muséum d'Hist. nat. de Strasbourg,* t. iv. (1850) p. 145. References to the glacial phenomena of the Vosges occur in other papers by this author, but the general results of his observations are given in his classical work, *Preuves de l'existence d'anciens Glaciers dans les vallées des Vosges, &c.* 1847.

[6] *Bull. Soc. géol. de France,* 3e Sér. t. i. (1873) p. 88; *Ann. du Club Alpin Français,* t. i. (1874) p. 308.

[7] *Verh. des 4. deutschen Geographentages zu München.* Berlin, 1884, p. 9.

[8] *Mittheil. der Commission für die geolog. Landes-Untersuchung von Elsass-Lothringen,* Bd. ii. p. 18.

perched blocks, and moraines occur more or less abundantly in the upper reaches of most of the mountain-valleys, but are best developed in those that descend to the west. Thus in the valleys of the Moselle, Moselotte, and Vologne there is evidence of very considerable glaciation. The old glacier of the Moselle, for example, flowed for a distance of twenty-five miles, and piled up its terminal moraines below Remiremont, about 1,250 ft. above the sea. At the south end of the chain glaciers, five or six miles in length, descended in the direction of Belfort; while that of the Thur Valley deposited its end-moraines near St. Amarin, at a distance of nine miles from its source. On the eastern slope of the mountains the glaciers were smaller. Thus at the head of the Munster Valley we see the terminal moraines of two, each of which attained a length of three miles. At the northern end of the chain no conspicuous moraines appear in the mountain-valleys.

The morainic mounds in the high valleys of the Vosges, like those occupying corresponding positions in the High Tatra, the Riesen-Gebirge, and other mountain-ranges in Central Europe, are so fresh and well-preserved that one can hardly believe they date back to the earlier stages of the Glacial Period. From what we have learned as to the successive invasions of northern Europe by great *mers de glace* we are prepared to meet with similar evidence of recurrent glacial epochs in the mountain-ranges referred to. Already, as we have seen, the facts connected with the glaciation of the Riesen-Gebirge and the Black Forest lead to the conviction that those regions have supported glaciers at successive epochs. The same holds true of the Vosges.

M. Collomb many years ago described the occurrence of erratic blocks at lofty elevations in those mountains, which could not have been transported into their present positions by any of the local glaciers whose moraines now form such conspicuous objects in the bottoms of the valleys. They are met with near some of the highest summits, such as the Ballon de Guebwiller, the Ballon d'Alsace, the Drumont, and the Hoheneck, up to a height of 1,000 metres above the valley. The blocks are rounded, weathered, and of a different

rock from that on which they rest. They are not striated and have all the appearance of being extremely ancient, their surfaces being much corroded. They cannot possibly have rolled down from above; their situation on elevated cols quite excludes that supposition. Their external aspect is so different from that of the erratics of the lower region—from which they are separated by a zone 500 metres in breadth, over which very few erratics are sprinkled—that it is difficult, M. Collomb says, to admit that they belong to the same period. If they were carried by ice the glaciers of the Vosges must have filled the valleys to overflowing, and, escaping from the mountain-region, must have deployed upon the great plains of the Rhine.

Some years later M. Daubrée gave an account of certain erratic deposits—moraine-like accumulations of blocks and boulders—which he found at various places in Lower Alsace, as between Dambach and Oberehnheim, at the foot of the mountains. It is only recently, however, that the full meaning of these erratic deposits has been realised. We now learn from the researches of Dr. E. Schumacher and his colleagues on the Geological Survey of Alsace and Lorraine that the Vosges have experienced several successive glaciations.[1] They show that all the morainic débris of the mountain-valleys which is heaped up into lateral and terminal moraines belongs clearly to the latest epoch—that, namely, of the 'youngest diluvium.' But much of the glacial material is not thus heaped up, and from the mode of its occurrence and its position it cannot be the product of the small glaciers whose end-moraines form such prominent objects in the high valleys of the Vosges. Thus, as Collomb had already shown, it covers the mountain-slopes up to heights much above the levels reached by the lateral and terminal moraines of the later glaciers. Not only so, but it may be followed down the valleys beyond the lowest terminal moraines into regions which the later glaciers never invaded. A very interesting and suggestive observation was made by Dr. van Werveke and confirmed by Dr. Schumacher and others. At Wesserling the terminal moraines rest upon a

[1] *Mittheil. d. geolog. Landes-Anst. v. Elsass-Lothringen*, Bd. iii. Hft. 2, 1892.

terrace of fluvio-glacial gravels, which continues down the valley where it overlies a striated rock-surface. This latter thus clearly points to an earlier glaciation.

Schumacher shows that the 'diluvial' deposits of the Vosges region group themselves readily into a lower, a middle, and an upper series. The lower or oldest accumulations are unstratified arenaceous clays or loams, crowded with blocks and boulders of various Vosges rocks. They appear capping rising grounds at and between the mouths of the mountain-valleys, and they cloak the hill-slopes that overlook the plains of the Rhine. It is these accumulations which were long ago recognised by Daubrée as 'dépôts erratiques.' All the erratics have come from the Vosges, but Dr. Schumacher points out that at the time of their formation the 'Buntsandstein' (one of the rock-systems of the Vosges) must have extended over a district where it no longer exists *in situ*. In other words, great denudation has taken place since the oldest diluvium was accumulated.

The 'middle diluvium' of Alsace is represented on the low grounds at the foot of the mountains by fluvio-glacial gravels which pass laterally into and are thus of the same age as the 'high-level gravel-terrace' of the Rhine. Opposite the mouths of the Vosges valleys this terrace is composed of coarse gravel charged with blocks and boulders. All these have come from the mountains; but, unlike those of the 'older diluvium,' they show that, at the time of their transport, the extension of the Vosges rock-formations did not differ from the present. Thus it is clear that the great denudation referred to in the preceding paragraph was in chief measure completed before the deposition of the middle diluvial deposits. These latter are clearly distinguished from and cannot be confounded with the 'oldest diluvium,' but form a distinct terrace-system which can be followed into the mountain-valleys. In some places they are represented by an unstratified clay-like mass, abundantly charged with angular fragments and large boulders, and showing here and there many blocks piled thickly together. All the included erratics are from the Vosges. Although the 'middle diluvium' thus occasionally resembles the 'older diluvium,' yet the character of its contents suffices to distinguish it from the latter; while

its connection with the 'high-level gravels' of the Rhine can be distinctly traced.

The youngest diluvial deposits of Alsace form broad flats in the Rhine Valley, whence they may be followed far up the mountain-valleys, where, as I have already stated, they are associated with the end-moraines of the later glaciers.

Thus, according to the geologists of Alsace, the Vosges have experienced three separate glacial epochs, of which the last was the least important.[1] That of the 'middle diluvium' appears to have been the most excessive—its fluvio-glacial gravels being obviously contemporaneous with the high-level gravel-terrace of the Rhine which in North Switzerland is associated with the great moraines of the 'outer zone.'

I have purposely avoided all reference to the interglacial deposits of this interesting region, because that would involve the discussion of a subject which is better reserved to a subsequent chapter. The interglacial beds do not occur amongst the morainic accumulations of the mountains, but are intercalated between the fluviatile deposits of the Rhine Valley. They will therefore be considered along with similar formations which occur in other parts of Europe outside of the glaciated areas.

Returning now to the Black Forest we find that the terminal moraines of that region, like those of the Vosges, belong to a late phase of the Glacial Period. Long ago Vogt and Dolfuss-Ausset[2] recognised that morainic débris and erratics from the Black Forest were scattered broadly over the low grounds, far beyond the limits reached by the lowest terminal moraines in the mountain-valleys. Indeed, the wide distribution of these materials towards the south leads to the conviction that the glaciers of the Black Forest eventually coalesced with the great ice-flows of Switzerland. Not only do large quantities of morainic débris from the former region cumber the northern slopes of the Rhine Valley, but scattered blocks of the same origin occur in the

[1] The geologists of Alsace think they have evidence of a yet earlier glaciation of the Vosges than that of the 'older diluvium.' That early glacial epoch they assign to the Pliocene Period.

[2] *Course dans la Forêt-Noire en* 1846.

ley of the Frick on the south side of the Rhine.[1] It would m, then, that at the climax of the Ice Age the southern ıks of the Black Forest were mantled in more or less ıtinuous ice.

Professor Fraas, who first called attention to the evidence glacial action in the valleys of the Nagold and the Ens, has) maintained that glaciers have flowed from the Swabian a. He describes the hill-tops as almost everywhere covered h shattered rock-débris—great blocks and slabs being in ces piled up together—while sheets of various diluvial de-its extend for long distances down the hill-slopes. These he takes for a kind of ground-moraine, but they seem to tain no large erratics and no striated stones; so that we st agree with Professor Partsch, who thinks that further of of glacial action is required. One cannot doubt, how-r, that the 'diluvial' deposits described by Fraas as being bundantly developed in the Swabian Jura, and by Gümbel occurring plentifully in the Franconian Jura, have been ived from the disintegration and breaking-up of the rock-sses of those regions. It is quite certain, also, that this k-débris has travelled from higher to lower levels. Its nsport cannot be due to river-action, and one is inclined, refore, to agree with Fraas that ice in some form or other been one of the agents employed in its formation and tribution. Possibly, some of the 'diluvial' deposits in stion may have had an origin similar to that of the ead' and 'chalk rubble' of southern England. But, how-r that may be, it is impossible to believe that the region ler review, which reaches elevations of 1,000 ft. to 3,000 ft. l more, could have escaped severe climatic conditions.

The facts now set forth may suffice to convince the der that the morainic accumulations of the mountain-areas Central Europe cannot be assigned to one and the same ge of the Glacial Period. Obviously they point to suc-sive glaciations; but the evidence is not so complete as may expect it to be, when each individual area has n ransacked as carefully as the Vosges and the Black rest. I am not aware that interglacial deposits have been

[1] Mühlberg, 'Ueber die erratischen Bildungen im Aargau,' &c. *Festschrift Aarg. naturf. Ges. z. Feier ihrer 500. Sitzung am 13. Juni 1869.*

discovered in the glaciated valleys of any of these mountain-regions. The only evidence of the kind that I have met with is that adduced by Herr Struckmann in his description of the Einhorn Cave, near Scharzfeld in the Harz. The cave, according to him, appears to have been originally a simple open cleft in the rocks, which was subsequently widened by the action of the water escaping from a narrow glacier in the immediate neighbourhood. The walls of the cave show funnel-shaped depressions with spiral flutings, which seem to indicate some such action. After the glacier retired, the cave was occupied by man, who brought hither the proceeds of the chase. Lastly, the glacier again advanced, when the descending water swept bones and other débris from the front part of the cave into its further recesses.[1]

Before leaving the mountains of Middle Europe attention may be directed to the distribution of cirques and rock-basins, which are of such common occurrence in those regions. Professor Partsch has pointed out that these are always best developed in the areas where independent evidence of glacial action is most conspicuous. And he notes the suggestive fact that as we pass from west to east cirques and glacial lakes occur at higher and higher levels. Thus the lowest-lying cirque-valleys are met with in the Vosges at a height of 570 metres, in the Black Forest at 750 metres, in the Bohemian Forest at 930 metres, in the Riesen-Gebirge at 1,030 metres, in the Altvater-Gebirge[2] at 1,200 metres, in the High Tatra at 1,500 metres. Here we have evidence that the snow-line in glacial times gradually rose to higher levels as it passed from west to east into the interior of the Continent. For, as we have already seen, corries and corrie-lakes must be taken as evidence of glacial action; and this evidence, in the case of the mountains of Middle Europe, goes hand in hand with that furnished by moraines, rock-striæ, and other glacial phenomena.

[1] *Archiv für Anthropologie*, Bd. xiv. p. 191.

[2] In the Altvater Mountains we have as yet no positive proof of glacial action, such as rock-striæ and moraines afford. But, as Professor Partsch points out, even in our own day the snow does not disappear from the highest-lying portions of this range until well into summer. Thus it is not difficult to believe that, under the influence of a colder climate, perennial névé and even glaciers may have existed in those mountains. (See *Die Gletscher der Vorzeit*, p. 179.)

n the present state of our knowledge it would be pre-ıre to attempt any correlation of the glacial accumulations ıose mountains with the diluvial deposits of northern ɔpe save in a general way. The Riesen-Gebirge, the ges, and the Black Forest are, indeed, the only ranges ch have yielded evidence of a complex glacial succession lar to that furnished by northern Germany, &c. As I l point out in the next chapter, it is now well ascertained each of the series of great terminal moraines which ır in the low grounds opposite the mouths of the Alpine eys is associated with a distinct terrace of fluvio-glacial 'els. The two later terraces are known in North Switzer- as the high-level and the low-level gravels respectively. se terraces pass down the valley of the Rhine, and with ı, as we have seen, the fluvio-glacial gravels of the Vosges the Black Forest are contemporaneous. How closely glacial succession of the Alpine Lands tallies with that orthern Europe we shall learn presently.

Vith regard to the other mountains of Middle Europe, ve can say at present is that the terminal moraines in r higher valleys are most probably on the same geological zon as the similar small moraines in the upper valleys of Black Forest and the Vosges. And these, I think, are t probably contemporaneous with the great terminal 'aines of Finland and the Baltic Ridge, and with the dis- t ground-moraines of the mountainous areas of our own nds. The earlier and more extensive glaciation to which e mountains have been subjected was doubtless syn- mous with the appearance of the Scandinavian inland ice e low-grounds of Germany. Those regions, as we know, e invaded twice by a *mer de glace*; and it is probable, efore, that the mountains of Middle Europe were con- poraneously covered with snow and ice. In the Riesen- irge moraines appear on three separate horizons. Those ch occur at the lowest levels were doubtless laid down ng the epoch of maximum glaciation in Europe. The t succeeding series belongs in like manner to the epoch of lesser *mer de glace* of North Germany, &c., while the ngest series may with much probability be assigned to epoch of the last great Baltic glacier.

CHAPTER XXXIII.

GLACIAL PHENOMENA OF THE ALPINE LANDS.

Typical deposits of the region—ground-moraines, terminal moraines, and fluvio-glacial gravels—Interglacial and glacial deposits of Val Borlezza, Leffe, Gandino, and Monte San Salvatore—Hötting breccia and its associated glacial accumulations—Glaciation of the Engadine—The old glacier of the Rhone; thickness of the ice; erratics and nunatakkr of the Jura; deflection-basin of Lake Neuchâtel; terminal moraines of the old Rhone glacier in the low-grounds of France—Glaciation of the mountains of Savoy and Dauphiny—The north branch of the great Rhone glacier—Other great glaciers of the Alpine Lands.

THERE is no region where the marks left by the gigantic glaciers of the Ice Age have been more assiduously studied than in the Alpine Lands. Besides the many eminent native geologists who have devoted themselves to this subject, hosts of enthusiastic visitors from a distance, some of them men of great distinction, have won for themselves scientific laurels amongst the glaciers of that beautiful region. For us especially the Alpine glaciers, ancient and modern alike, have many valuable lessons. Geologists in this country have frequently been puzzled to decide what glacial phenomena here ought to be ascribed to the action of land-ice, and what to rafts and bergs. In the Alpine Lands nowadays there is no such difficulty. Glacialists are unanimous in considering that all the marks of old ice-action in those regions are the work of glaciers alone. Rock-scratching on the grandest scale—striæ running across the tops of considerable hills—erratics which have crossed deep broad valleys, often for great distances, and stranded at last on steep mountain-slopes—till, formed and accumulated under ice (a process which some geologists even yet cannot be persuaded has ever taken place), may all be studied to the greatest advantage in the Alpine Lands. It is not my purpose, however, to dwell much upon these matters. The object I have in view is

simply to indicate the succession of the glacial deposits, for the purpose of comparing these with glacial accumulations elsewhere. But before attempting to give the general results arrived at from a study of the glacial phenomena of the Alps, it may be well to point out, however briefly, the general character of the deposits that marked the advance and retreat of the great glaciers. I shall consider these deposits under the three heads of (1) Ground-moraines, (2) Terminal moraines, and (3) Fluvio-glacial gravels.

1. Ground-moraines.—The ground-moraine, or *moraine profonde*, of the Alpine Lands is precisely similar to the boulder-clay of Northern Europe, as the following brief description will show. In every region where it occurs its colour is influenced by that of the principal rock-masses. Thus in the low-grounds of Switzerland, in the valley of the Rhone below Geneva, and in the valleys of the Arve and the Isère, where the chief rocks consist of limestone, black shale, schists, and slates, the deposit in question is dark-coloured. Similarly it varies in consistency according to the nature of the rocks from which it has been derived. Sometimes it is decidedly a clay, more or less tough, at other times it is gritty, arenaceous, and less coherent, even passing into sand. Its included stones are evidence likewise that the ground-moraine has travelled outwards in the direction of the principal valleys. They vary in size from the smallest fragments up to large blocks many yards in diameter, but these last are more common in the ground-moraine of the mountain-valleys than in that which cloaks the low grounds at the foot of the Alps. In the last-named region the stones do not usually exceed two or three yards in diameter —the larger number hardly averaging more than six inches. They exhibit normal blunted subangular forms, and are rubbed, scratched, and polished either all over, or, as is not infrequently the case with the larger boulders, on one or two sides only. All are not equally well dressed. Thus granite, gneiss, many schists and igneous rocks are often only faintly striated, while limestones and other close-grained compact rocks are almost invariably well polished and glazed. Here and there 'boulder-pavements' occur—the boulders being scratched and smoothed in one and the same direction. One

may note also, that marine shells have been detected in the ground-moraines near Lyons,[1] and again in similar accumulations near Como.[2] These shells, however, are of Pliocene and Miocene species, and are clearly derivative, like the similar occurrences in the boulder-clays of Northern Europe. Ground-moraine varies in thickness from a yard or less up to 150 or even 200 ft.; in a few places it reaches 300 ft. As a rule it is quite unstratified, but the thicker masses occasionally show a kind of rudely bedded arrangement, especially when viewed from a little distance. Frequently seams and thicker beds of boulders, shingle, gravel, grit, sand, and clay interosculate with the ground-moraine, and are often highly confused and contorted. In other places, however, such inclusions appear undisturbed, and may attain a thickness of many feet or yards. Now and again the ground-moraine assumes a pseudo-laminated structure—a structure which is obviously not due to water-action, for the stones and boulders intersect the laminæ at all angles. The laminæ referred to are often puckered and crumpled, and upon being separated show smooth and polished surfaces. Irregular joints also may intersect the stony clay—the faces of the joints exhibiting the same smooth and polished appearance. In many places the deposit rests upon a shattered and jumbled rock-surface, and when such is the case, the lower portion of the accumulation is largely made up of the crushed and broken débris of the subjacent rocks. More frequently, perhaps, the underlying rock shows a striated and polished surface—in some places large pot-holes (giants' kettles) being exposed upon the removal of ground-moraine.[3] In the low-grounds

[1] Falsan, *Bull. Soc. géol. de France*, 3^e Sér. t. iii. p. 727; A. Locard. *Description de la Faune malacologique des terrains quaternaires des environs de Lyon*, 1879.

[2] Stoppani, *Rivista Italiana*, August 1874; *Atti Soc. Ital. di Scienze natur.* April 1875; *Geologia d'Italia*, Pte. 2^a, p. 131. Stoppani maintained that the shells were *in situ*, and that the great moraines of Northern Italy had been deposited in the sea of Pliocene times. His views received support from E. Desor (*Le Paysage morainique*, 1875), and Prof. Renevier (*Bull. Soc. géol. de France*, 3^e Sér. t. iv. p. 187), but have been successfully controverted by Prof. Rütimeyer (*Ueber Pliocen- und Eisperiode auf beiden Seiten der Alpen*, p. 187) and M. Mayer (*Bull. Soc. géol. de France*, 3^e Sér. t. iv. p. 199). In 1878, after going over the sections near Como, I came to the same conclusions as MM. Rütimeyer and Mayer, and a subsequent visit (in 1889) only confirmed me in the opinion that the shells are of derivative origin.

[3] These are seen in the well-known 'Gletscher-Garten' at Lucerne: excellent examples also occur at Lauterach near Bregentz at the head of Lake

latter often reposes upon a thick sheet of fluvio-glacial 'el and shingle, and the same is occasionally the case in mountain-valleys. In the main valleys the stony clay ' attain locally a considerable thickness, and extend con- .ously for some distance, forming interrupted terraces that . off up the mountain-slopes. In the narrower and steeper isverse valleys it occurs only in patches of very limited ›nt. Such patches may be encountered at very consider- heights. Thus Favre records the occurrence of traces ground-moraine on the Schneestock at a height of 3,930 ;res. In the region of the Upper Engadine I have fre- ntly met with it at elevations of 1,700 to 2,000 ft. above bottoms of the valleys. But the ground-moraines attain ir greatest development upon the low-grounds that spread from the foot of the Alps. All the wide tract between se mountains and the Jura, for example, is more or less :kly covered with it. It likewise extends in broad sheets ng the northern front of the Alps, covering very consider- e areas in Southern Germany. Similarly it cloaks a large t of the low-grounds of Savoy and Dauphiny and the ldle valley of the Rhone in France, while round the rer ends of the great lakes of Italy it puts in a prominent earance.

Such, then, is the ground-moraine of the Alpine Lands. one who shall compare that deposit with the boulder-clay our own country will doubt that both have had a similar gin.

The old ground-moraines of the Alps, like the stony clays Northern Europe, bear witness to the erosive action of . In the case of existing Alpine glaciers, it is true, the glacial detritus must be derived to some extent from erficial sources—from the morainic matter engulphed crevasses. It was otherwise, however, with the ancient ciers. The vertical distribution of the ground-moraines, l the great elevation attained by *roches moutonnées*, ched blocks, and lateral moraines, demonstrate that the lleys were so deeply filled with ice that contiguous glaciers

nstance (Baron Seiffertitz and Steudel, *Schrift. d. Vereins z. Geschichte d. densees*, Bd. iii.); in the neighbourhood of Ueberlingen, near the lower end of e same lake (*Mittheil. d. deutsch. u. oesterr. Alpenvereins*, 1884, p. 276); and ar Bern (J. Bachmann, *Berner Mittheilungen*, 1874, p. 136).

frequently coalesced across the intervening mountain-ridges. Only the tops of the higher mountains of the Secondary Chain appeared above the level of the ice. Indeed, viewed from the north, the lower Alps at the climax of the Glacial Period must have appeared clad in one general ice-sheet, dotted with *nunatakkr*, beyond which would rise the snow-clad ridges of the Central Chain. All the great valley-glaciers were more or less confluent across the Secondary Chain. And yet the ground-moraines of those regions are crowded with local stones and blocks which could only have been detached by the action of the glaciers themselves. Ice or clay, or both, rammed and pressed into joints and other crevices in rocks, led to the rupture and dislocation of projecting ledges, and larger and smaller fragments thus wedged out were dragged forward and incorporated with the ground-moraines. Again and again one comes upon shattered and jumbled rock-surfaces underneath ground-moraine, the lower portions of which indeed graduate down into the rock-débris. According to MM. Penck, Brückner, and Böhm, the larger portion of the materials forming the wide-spread ground-moraines of Tyrol are the direct product of glacial erosion. It is admitted, of course, that the loftier ridges of the Central Alps remained above the surface of the *mers de glace*, and from these superficial detritus must have been showered in abundance. It may well be doubted, however, if any considerable portion of this rock-débris ever found its way into the ground-moraine. Crevasses would hardly penetrate the whole thickness of the ice, which in many valleys reached a depth of 2,000 or 3,000 ft., and even in some places of 5,000 ft.[1] After making allowance for the supply of materials from all superficial sources, and for the incorporation of terminal moraines, fluviatile detritus, and preglacial detritus of every kind, we must yet admit that all these form only a small proportion of the ground-moraines. The bulk of the materials, which, like those of our own boulder-clays, consist of unoxydised rock-rubbish, have been

[1] The occurrence of giants' kettles in the low-grounds of Switzerland may seem to show that here and there communication was established between the upper surface and the bottom of the ice, even where the *mer de glace* was thickest. But I suspect that giants' kettles at such low levels were formed during the decadence of the ice-flows, when the general forward movement had been arrested, and the more or less inert mass was breaking up and melting more or less rapidly.

erived from the subjacent rock-masses by the ice itself. he great thickness attained by the ground-moraines, and the ide extent of country over which they are distributed, thus ve us some faint idea of what is meant by glacial erosion. ccording to Professor Penck, the ancient glacier of the sar occupied an area 4,600 square kilometres in extent, of hich 1,800 square kilometres at least are covered with round-morainic materials, reaching upon an average some 0 metres in thickness. This gives a mass equalling 36 ubic kilometres, derived from a region 2,800 square kilo- netres in extent. In other words, the surface of this region as been lowered by as much as 13 metres. Or, in Brit- sh measurement, a thickness of 42 ft. 8 ins. of rock has een eroded from a surface 1,080 square miles in extent. But this estimate takes no account of the ancient fluvio- glacial gravels, which, as we shall see presently, have been lerived chiefly from the materials of the ground-moraine, nor does it include the fine sediment which the old glacier-rivers carried away in suspension.[1] Professor Heim has estimated that in the drainage-system of the Reuss, above the Urner See, a region in which water is enabled to exert great erosive power, the surface of the land is lowered by denudation to the extent of 1 metre in 4,125 years. At this rate, as Dr. Penck remarks, it would take running water 53,625 years to lower the level of the Alps of North Tyrol by 13 metres—the work accomplished by such glaciers as that of the Isar. The same geologist refers to the observations of M. Dolfuss-Ausset on the quantity of silt contained in the river that issues from the Unter-Aar glacier—observations which show that from this glacier (fifteen square kilometres in extent) 638 cubic metres of mud are carried out in one year. This fine mud, there can be no doubt, is the result of glacial grinding, and the amount annually removed shows that the Unter-Aar glacier lowers its bed by 1 metre in 1,666 years—an amount

[1] The amount of erratic materials brought down from the Alps and spread over the 'Vorland' between the Iller and the Inn is estimated by Penck as equal to 540 cubic kilometres—a mass weighing about 1,080,000,000,000,000 kilogrammes. For the transport of this material by rail, 4,000 million trains, each consisting of 25 fully laden trucks, would be required. The mean level of the 'Vorland' has been raised for 60 metres or thereabout by the deposition of these materials—while by their abstraction from the Northern Alps these mountains have been lowered about 36 metres. (*Der Tourist*, No. 1. (1882), p. 9.)

of erosion which it would take the rapidly-flowing water of the mountains 4,125 years to accomplish. Moreover, as Penck points out, in this estimate of the work performed by the glaciers only the fine mud carried in suspension has been considered—the coarser sediment rolled forward by the glacier-river is entirely ignored. Yet notwithstanding this, we see that the glacier erodes 2½ times more rapidly than running water.[1]

2. Terminal Moraines.—The farthest limits reached by the old glaciers are marked out by terminal moraines, which in many cases are well preserved. In those that occur on the low grounds opposite the great Alpine valleys that descend to the north ground-moraine is the dominant material. The reverse is the case with the Alpine glaciers of to-day—the terminal moraines of which are made up almost exclusively of rock-rubbish, derived from superficial sources. Their ground-moraines are comparatively insignificant, and thus add little to the bulk of the débris that gathers in front of the glaciers. With the ancient glaciers the conditions were different. So much rock was then drowned in ice that superficial matter bore a relatively small proportion to subglacial detritus. The ground-moraines attained a much greater thickness than those of the puny glaciers of our day—their larger mass being in a measure proportionate to the greater size of the glaciers. Hence it is that ground-moraine bulks most largely in the terminal moraines that mark the limits reached by the vast ice-streams at the foot of the Alps in France and Southern Germany. On the south side of the Chain, where, owing to the configuration and height of the mountains that approach the plains, the glaciers were seldom confluent even in their lower reaches, a relatively greater extent of rock-surface was available for the supply of superficial moraines.[2] Hence the terminal moraines at the foot

[1] The observations recorded at p. 38 show that the amount of material carried out from underneath some glaciers is greatly in excess of the above.

[2] The glaciers on the south side of the Alps did not attain the dimensions of those descending the northern slopes. The latter drained upon the whole a greater width of mountain-land, and the snow-line appears to have been depressed to a lower level in the north than in the south. The valleys that open on the plains of the Po have a less extensive gathering ground and a higher temperature, and they are, upon the whole, narrower and steeper. Thus their glaciers, although smaller than those of the northern valleys, had relatively larger terminal moraines.

;he Alps in Lombardy and Venetia contain a greater protion of loose angular débris and large erratics. Neverthewe still find ground-moraine entering strongly into their nation. Gravel and sand also are conspicuous ingredients, ndeed is the case likewise on the north side of the chain. ihort, it may be said that large erratic blocks and angular ris are most prominent in the terminal moraines of glaciers t drained regions where much naked rock was exposed. most striking of all the terminal moraines of the Alpine ıds are those of North Italy. The moraines of the Dora tea, for example, form a huge semicircular embankment osite the mouth of the large valley of Aosta, and some of their extent may be gathered from the simple statent that they rise out of the plains of Piedmont as steep s to a height of 1,500 ft., and even in one place to very rly 2,000 ft. Measured along its outer circumference, n Andrate by Mongrando, Saluzzola, Cavaglia, and Caluso he bridge over the Chiusella, this great morainic mass is nd to have a frontage of at least fifty miles, while the plain ch it encloses extends for some fifteen miles from Andrate thwards, with a breadth of about eight miles. Two lakes larger of which is little more than two miles long by mile broad) occur within the moraine.

3. Fluvio-glacial Gravels.—The large terminal moies of the Alpine Lands are everywhere dovetailed with usually rest upon more or less thick deposits of gravel— so-called 'alpine diluvium.' The origin of these gravels given rise to considerable discussion, but geologists now e that they are of fluvio-glacial origin. They are exactly parable to the sheets of gravel and sand which underlie overlie the boulder-clays in the low-grounds of Northern ope. Obviously they have been deposited by water escapfrom the glaciers. As we have already seen in the case he glacial deposits of the Vosges, the terminal moraines the fluvio-glacial gravels are of contemporaneous origin. connection between the two has been studied in great il by Dr. Penck in the Alps of Bavaria, and his conclus have been amply sustained by the researches of MM. ickner, Böhm, Blaas, and Du Pasquier. Each of the ıt morainic ridges has its corresponding gravel-terrace.

Standing on the summit of one of those ridges and looking away towards the low-grounds that sweep out from the mountains, we see the ridge below us sloping steeply down to a far-extended terrace—the upper surface of which may be 150 ft. or more above the level of the adjacent river. Thus in the vicinity of the terminal moraines of the Limmat in North Switzerland the terrace is 160 ft. and more above the river, but its surface gradually falls to 115 ft. at Turgi, whence it may be followed down the valley of the Aar into that of the Rhine, slowly sinking all the way, until at Bâle its surface is only some 95 ft. above the water.[1] The terraces are composed almost exclusively of materials derived from the upper reaches of the mountain-valleys—they consist of the same kinds of rock as the blocks and boulders of the moraines against which the terraces abut. In short, the gravel has obviously been derived from the morainic materials brought down by the glaciers. It is distinctly stratified and at a considerable distance from the moraines the stones are well water-worn and rounded. Advancing up the valley of the Rhine, or that of the Aar, the Reuss, or the Limmat, the gravel-stones gradually become larger and less distinctly water-worn, many being more or less subangular in shape. When at last the moraines are approached, the inclination of the upper surface of the terrace increases to 4° or 6°. Angular blocks now frequently appear, while at the same time the terrace-deposits become so tumultuously bedded that, as Dr. Du Pasquier remarks, they resemble modified morainic material. There is thus, as he shows, a gradual passage from the terraces into the moraines—the two deposits interosculate and merge into one another. Du Pasquier's observations confirm those made by Dr. Penck in the Bavarian plateau at the foot of the Alps. There, as in Switzerland, there is a passage from the moraines into the gravels. Now and again striated stones occur in the latter, but these are not met with at any distance from the moraines. This might at first sight appear surprising, seeing that the dominant materials of the moraines are of subglacial origin.

[1] Du Pasquier, *Beiträge zur geologischen Karte der Schweiz*, 1891; *Bull. Soc. d. Sciences nat. de Neuchâtel*, t. xviii.; *Bibl. Univ. Archives des Sci. phys. et nat.* t. xxvi. (1891) p. 44; t. xxvii. (1892) p. 219.

ut striated stones soon lose their glaciated surfaces in .nning water, as was pointed out long ago by Collomb[1] ıd Charles Martins,[2] the latter of whom showed that 328 ırds below the terminal point of the Aar glacier not a ngle scratched stone was to be seen in the bed of the ream. All the facts go to show, then, that the wide ıeets of gravel which sweep outwards from the terminal oraines are of fluvio-glacial origin. They have been depoted by the tumultuous waters escaping from the ancient aciers. It is obvious, therefore, that as a glacier advances ıto the low-grounds it will drop its moraines upon sheets f water-worn gravel: hence the origin of the 'alpine diluium' underlying the great terminal moraines.

Now let us look for a moment at the character of the round in the rear of these moraines. There we find no ·ace of the high-level terraces of which I have been speakıg. In place of them we see a broad amphitheatre-like epression, across which the river makes its way with many winding. This is what Professor Penck terms the 'central epression,' which may be 100 or 150 ft. below the level of ıe external gravel-terraces, and often contains one or more kes. It is, in short, the bed of the vanished glacier. luvio-glacial gravels are only sparingly developed in the ntral depression. During the advance of the glacier they oubtless formed a sheet covering this part of the valley, ıt were subsequently ploughed into and removed.

This short sketch of the three principal types of glacial eposit met with in the Alpine Lands may suffice to show ıat the former presence of a great ice-stream is indicated ot only by the occurrence of *roches moutonnées* and glaciated ones, by ground-moraines and terminal moraines, &c., but lso by aqueous formations—by broad terraces of gravel. Iaving premised so much, we may now proceed to consider he evidence bearing on the succession of events in glacial times. In the Alpine Lands, as in Northern Europe, interglacial deposits are met with—the interglacial beds of

[1] *Comptes-rendus hebd. des Séances de l'Acad. des Sciences*, t. xx (1845) p. 1718; *Bull. Soc. géol. de France*, Sér. ii. t. iv. p. 301. By agitating scratched stones in water charged with sand, the striæ were removed in a few hours.

[2] *Revue des deux mondes* (1847), i. p. 706.

Switzerland having been recognised as such before the significance of those in other countries had dawned upon geologists.

I have elsewhere given an account of the Pliocene lignites which occur in certain mountain-valleys in North Italy.[1] These accumulations were long ago described by Stoppani, whose conclusions I have been able to a large extent to corroborate. The beds referred to are met with in the Val Borlezza, which opens upon Lake Iseo, and at Leffe on the Romna, one of the tributaries of the Serio. The deposits in the Val Borlezza are of lacustrine origin. Amongst the plant-remains obtained from them are *Magnolia*, sp., *Acer pseudo-platanus*, L., var. *paucidentata*, *Buxus sempervirens*, *Ulmus campestris*, *Taxus baccata*, *Phacidium buxi*. The white marl containing these plants has also yielded bones of fish (undetermined) and of *Rhinoceros hemitœchus*, Falc. At Pianico (the lower end of the old lake) the succession of deposits is as follows :—

4. Glacial morainic deposits.
3. Lacustrine marl with *Rhinoceros hemitœchus*, plants, &c.
2. Clay passing down into silt and sand, containing sporadic stones.
1. Sand, &c., abundantly charged with glaciated stones.

The old lake in which these beds accumulated owed its origin unquestionably to the damming of the Val Borlezza by the great glacier of Lake Iseo and that branch of it which crossed over into the Val Cavallina. The bottom-beds of the lacustrine series are composed of glacial clay and silt, containing at Pianico, where the series is deeply trenched by the stream, scattered glaciated stones, which become more numerous towards the base of the section, where the sandy mud or muddy sand is abundantly charged with them. All these deposits must have gathered there while the mouth of the Val Borlezza was barred by the glacier. Eventually, however, that glacier melted away, and left behind it an embankment of morainic detritus, which for some time continued to act as a dam ; but the lake, as it overflowed, sooner or later cut that impediment across, and so drained itself. The trenching of the bar, however, would be a slower process than might be supposed. The remains of the morainic em-

[1] *Prehistoric Europe*, p. 303.

bankment are still found clinging to the slopes of the mountains in the form of a mass of indurated conglomerate and coarse débris; and it is highly probable that long before the glacier had disappeared much of its moraine may have become thus consolidated by the action of infiltrating water. Many of the rock-fragments are limestone, while the hills around consist largely of calcareous strata. We are not to suppose, therefore, that the bar of morainic detritus would be as readily cut through as one composed of the débris of crystalline rocks in a country where the superficial water contains only a small percentage of calcareous matter in solution. At all events it would appear that long after the great glacier of Lake Iseo had vanished, the lake continued in existence and a genial climate prevailed—the surrounding hills being clothed with maples, elms, yew, box, and other forms, while the rhinoceros became a native of the district. Eventually, however, these genial conditions came to a close, once more the Val Camonica filled with ice, and the glacier dilating into the Val Borlezza deposited its lateral moraine upon the surface of the fossiliferous lacustrine deposits. The advent of milder conditions and the final dissolution of the glacier permitted the river Borlezza to cut the deep narrow trench through which its waters now rush to join Lake Iseo.[1]

A few miles west of the Val Borlezza we come upon the relics of another interglacial lake, formed by the damming up of the Val Gandino which opens upon the valley of the Serio. The upper reaches of the latter were formerly occupied by a large glacier from which a torrential river carried down immense quantities of sand, gravel, and shingle. These materials now form banks and terraces that fringe the flanks of the Val Seriana up to a great height above its present bottom. One can trace them down the valley beyond the mouth of the Val Gandino, across which they extend, forming a high bar, which, as viewed from the road in the Val Seriana, has much the appearance of a terminal moraine. But, as

[1] As might have been expected, lakes appear frequently to have come into existence in the Alpine Lands during the Glacial Period. Whenever a valley was dammed up by a glacier entering it from some adjacent valley, a glacial lake was necessarily formed. As an example I may cite the Piano di Silvanera, near Cogne, in the valley of Aosta, which represents a lake formed by the advance of the ancient glacier of Valnontey into the valley of the Grand Eyvia. (Dr. F. Virgilio, *Atti R. Accad.* (*Parte fisica*) vol. xxi. p. 195.)

Stoppani has shown, this bar is made up of shingle, gravel, and sand, the greater portion of which has certainly come down the Val Seriana—the bar, in short, is a great lateral *cône de déjection* of the river Serio. It now presents a steep face to the Val Seriana, where it has been undercut by the river in the process of lowering its bed. But its upper surface still slopes away from the Val Seriana into the basin of Gandino, which latter has quite the appearance of an old lake-bottom, bounded as it is on all other sides by rough steep mountains. That basin is now drained by the Romna, which has cut its way down across the bar. The whole surface of the valley of Gandino is covered with gravel and shingle, now for the most part hardened into conglomerate, consisting of materials derived from the limestone and porphyry of the surrounding mountains. Underneath the conglomerate come lacustrine clay and silt, with intercalated layers of shell-marl and seams of lignite or brown coal—one of which attains a thickness in places of thirty feet. Amongst the plants obtained from the lignites at Leffe are *Pinus*, sp., *Abies excelsa*, *A. Balsami*, *Larix europæa*, *Corylus avellana*, *Acer tribulatum* (?), *Æsculus hippocastanum*, *Juglans bergomensis*, *Trapa natans*, *Folliculites neuwirthianus*. The walnut-tree is met with in greater abundance perhaps than any of the others—its fruits occurring plentifully. According to Sordelli the flora indicates a climate as genial as that of the plains of Lombardy and Venetia. The mammalian remains found associated with the lignite beds have been referred by Dr. Forsyth Major to the following species :—*Elephas meridionalis*, *Rhinoceros leptorhinus*, Cuv., *Bos etruscus*, *Cervus* (two species), *Castor europæus* (?), *Arvicola*, sp. All the shells obtained belong to species still living in Lombardy (*Valvata piscinalis*, *Planorbis complanatus*).

The overlying conglomerate is doubtless of torrential origin. It is disposed in broad terraces, the surfaces of which are inclined outwards or down the Val Gandino to the gorge of the Romna, which now disjoins the great bar from the mountain-slope against which it formerly abutted. A distinct unconformity separates the lignite-beds from the conglomerate (see Fig. 76), which has clearly been deposited under very different conditions.

The succession of changes which the facts thus shortly stated seem to indicate is quite in keeping with the evidence supplied by the accumulations of the Val Borlezza. First, we have a lake formed in the Val Gandino by the deposition of a great bar of fluvio-glacial deposits across its lower end. Long after the glacier of the upper Val Seriana had disappeared and the Serio had resumed its normal flow, the bar of river-detritus continued more or less intact, the loose shingle, gravel, &c., having in time become consolidated and hardened into conglomerate, in the same manner and for the same reasons as the morainic dam at Pianico. The climate eventually waxed extremely genial, and a flora comparable

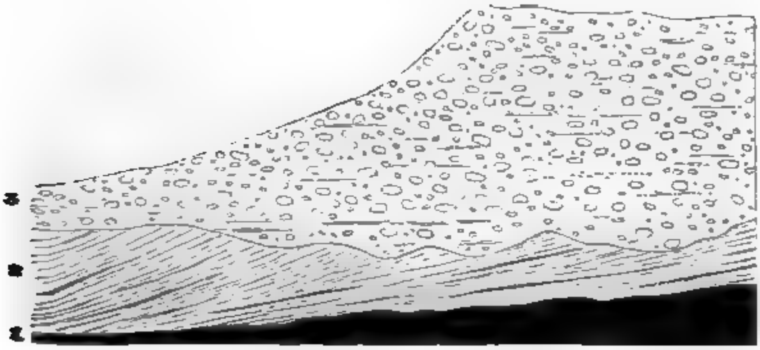


Fig. 76.—Section of Interglacial Beds at Leffe, Gandino.
1, Lignite; 2, Silt, clay, &c.; 3, Shingle and gravel.

to that of the plains of Lombardy clothed the bottoms of the valleys and the lower slopes of the mountains, while the southern elephant and its congeners roamed over the district. During the epoch of genial conditions the lake was gradually silted up. Then once more the climate changed, and flooded streams and torrents flowed over the surface of the dried-up lake, ploughing at first into its sediments, but eventually burying these deeply under a thick accumulation of coarse shingle and gravel. No glacier seems ever to have flowed into the Val Gandino, but we may readily believe that, while the adjacent Valle Cavallina and Lake Iseo were filled with ice, the mountains overlooking Gandino must have been more or less deeply snow-clad. It is to the melting of such snow-

fields in summer that the torrential gravels overlying the Leffe lignites were probably due.[1]

It will be observed that the phenomena now described cannot be accounted for by supposing a slight oscillation or advance and retreat of the glaciers. With the great glacier of the Val Camonica occupying the basin of Lake Iseo the climatic conditions must have been adverse to the growth of walnuts, laurels, and maples in the adjacent Alpine valleys. The flora of the lake-beds indicates a climate, as we have seen, like that of the plains of Lombardy, and when that flora lived in the mountain-valleys of Borlezza and Gandino, the snow-fields of the Alps could hardly have been more extensive than they are at present. In short, we have here clear evidence of two glacial epochs separated by a long interglacial stage.

To the same interglacial epoch, possibly, may be assigned the lacustrine beds described by Professor C. Schmidt as occurring on the northern slope of Monte San Salvatore overlooking Lake Lugano.[2] The section shows at the base crystalline schists which are overlaid by well-bedded clays of Pliocene age. Upon these last rests characteristic ground-moraine crowded with scratched stones, and reaching a thickness of 100 ft. or thereabout. Overlying this glacial mass comes a distinctly bedded greyish-yellow sandy deposit, six and a half feet in thickness, and containing many fragments of lignite and numerous small fresh-water shells. The bed occurs at a height of 328 ft. above the surface of Lake Lugano. The shells are rather fragile. Amongst them Pro-

[1] The late Professor Stoppani was of opinion that the fossiliferous sediments of the lakes of Borlezza and Gandino were laid down while the great glaciers and flooded rivers were in existence. As I have shown elsewhere (*Prehistoric Europe, loc. cit.*), it is impossible to believe that the flora and fauna of the lignites and lake-sediments could possibly have existed in those mountain-valleys under such conditions. A lake like that of Borlezza, dammed by a glacier and fed by cold and muddy glacier-water, and by numerous lateral torrents flowing from snow-clad heights, could not have been tenanted by fish and those numerous microscopic organisms whose calcareous skeletons form a pure white marl. The lakes undoubtedly came into existence under glacial and fluvio-glacial conditions, but they persisted during a long interglacial epoch. The presence of morainic and fluvio-glacial detritus resting upon the lake deposits demonstrates that glacial conditions again supervened. I may add that my views as to the interglacial position of these Italian lacustrine deposits have recently been confirmed by Professor Penck and Dr. Du Pasquier.

[2] *Eclogæ Geologicæ Helvetiæ*, vol. ii. (1890) p. 50.

sor Andreæ recognises *Bythinia tentaculata* and *Valvata* *·opidina*), sp.—all very small examples. A number of bryonal forms have not been determined. Spicules of nges occur, as also various species of diatoms which are l found living in fresh and brackish water. Above the sh-water beds lies a second ground-moraine—some 230 ft. thickness. According to C. Schmidt, the succession of nges suggested by this section is as follows:—Long after disappearance of the Pliocene sea a glacier advancing n the east piled up the lower ground-moraine. The glacier n retreated, and a little lake occupied a hollow in the ex-ed moraine. The character of the organic remains and general poverty of the fauna are indicative of somewhat genial conditions.

The overlying moraine points to another advance of the cier. If the lacustrine deposit is correctly assigned to the ne epoch as the interglacial beds of Gandino and Borlezza, vas probably laid down either at the beginning of that och, before the climate had become warm and genial, towards its close, when glacial conditions were again minent.

Another interesting interglacial deposit is that of Hötting, posite Innsbruck.[1] This consists of a thick sheet of breccia ich from time to time has yielded plant-remains. The k is composed of angular and subangular fragments of omite, sandstone, &c., obviously derived from the heights ove. In short, the breccia is simply the *cône de déjection* mountain-torrents, subsequently indurated by the action infiltrating water. Beginning at a height of several usand feet above the bottom of the valley, it sweeps down mountain-slopes, and spreads out over a well-marked race, that rises some 430 ft. above the surface of the Inn. cellent sections of the rock are exposed along the edge of

[1] The following are the more important papers, &c., descriptive of the ting beds and flora:—Pichler, *Ferdinandeums-Zeitschr.* iii. Folge, 8. Heft; ck, *Die Vergletscherung der deutschen Alpen*, p. 228; *Verhandl. d. k. k. og. Reichsanst.* 1887, No. 5; Böhm, *Jahrb. d. k. k. geolog. Reichsanst.* 4, p. 147; Blaas, *Ferdinandeums-Zeitschr.* iv. Folge, 29. Heft; *Bericht nat.-wissensch. Vereins für* 1889, p. 97; Ettingshausen, *Sitzungsber. d. k. idem. d. Wissensch. Wien*, Bd. xc. Abth. i. p. 260; Unger, *Ferd.-Zeitschr.* Folge, 9. Heft; Stur, *Abhandl. d. k. k. geolog. Reichsanst.* Bd. xii. No. 2; v. Wettstein, *Sitzungsb. d. k. Akadem. d. Wissensch. Wien*, Bd. xcvii. th. i.; *Die fossile Flora der Höttinger Breccie*, 1892, Vienna.

this terrace, and in the numerous ravines which intersect it. It is rudely bedded, and here and there shows irregular pockets and inclusions of fine-grained materials, from which the plant-remains referred to have been obtained. From the character of these remains the breccia was classified by Adolph Pichler as probably of Miocene age, while Von Mojsisovics thought it was somewhat younger, and ranged it as Upper Tertiary. In 1882, however, it was shown by Albrecht Penck to be of interglacial age. This conclusion was at once challenged, on the ground that the flora had a Tertiary and not a Pleistocene facies. It was urged, therefore, that as all glacial deposits had hitherto been assigned to the Pleistocene, this particular breccia could not be of interglacial age. But this contention has not been sustained by the stratigraphical evidence; Penck's observations have been confirmed by such highly competent experts as MM. Blaas, Böhm, Du Pasquier, and Von Wettstein.

The breccia overlies a ground-moraine which is full of the usual striated and ice-worn erratics, many of them derived from the Central Alps (Urgebirgsgerölle). Above Schloss Weiherburg this superposition is well exposed in an open section upwards of 100 yards in length—the ground-moraine dipping into the hill under the breccia for twelve or thirteen feet, which is as far as the junction is laid bare. Penck points out that the moraine could not have been pressed or squeezed in underneath the breccia. The junction between the two is always sharply marked, and the ground-moraine contains not a single fragment of the overlying rock. This could hardly have been the case had the boulder-clay been intruded into its present position. I may remark further that the breccia has been cut back by denudation, and must formerly have extended over a wider surface. This is shown by the occurrence, for example, of the isolated mass of breccia which forms the upper portion of the Oelberg, about two-thirds of a mile south of the Weiherburg section. That outlier of breccia rests upon laminated clays, which are clearly of Pleistocene age, since they have yielded cones of *Pinus montana*. Again, immediately below Mayer's Quarry (half-way between the Oelberg and the Weiherburg section) the breccia appears superposed on shaly coal resting upon

d-moraine. In the ravine above Hötting the super-on of the breccia to ground-moraine is likewise visible, ere a bed of clay of Pleistocene age separates the two ıulations. From this clay (four inches thick) Professor ε obtained a few shells which were determined by ssor Sandberger, according to whom they are charac-.c Pleistocene forms (' sicher diluvial '). The shells are *villosa*, Drap., *H. tenuilabris*, A. B., *Pupa muscorum*, ıd *Cionella lubrica*, Müll. sp. Thus the breccia overlies ıly ground-moraine but deposits charged with the relics diluvial ' fauna and flora. All the sections now referred :ur below a height of 700 ft. over the river Inn, where :eccia (usually reddish in colour), with underlying and ring glacial accumulations, forms a conspicuous terrace. ı this red breccia is followed up the ravine above Hötting ventually overlaid by a white breccia, from which come .mous plant-remains whose character and probable age given rise to so much discussion. These plants I shall to presently; meanwhile let it be noted that the breccia ıich they occur is also underlaid by ground-moraine ;ting of local materials. The superposition of the .a is perfectly clear—indeed its lower portion seems to ısculate with morainic materials, and it certainly contains ɔd stones included in its mass. Hence there can be no whatever that both breccias overlie glacial accumula-

ırther, it is worthy of note that erratics derived from .ountains overlooking the head-waters of the Inn are of ıon occurrence in the breccias. They abound here and in the red breccia, and are met with in the white a up to a height of nearly 2,000 ft. above the river. ›bvious that such erratics could only have been derived pre-existing glacial accumulations. They are in short of the moraines which are seen cropping out from neath the red breccia. The presence of the local nes below the white breccia shows that before the ıulation of the latter, small glaciers must have descended orthern flanks of the Inn Valley opposite Innsbruck, : the mountain-slopes under existing conditions are free perennial snow and ice. When we bear in mind that

these heights hardly attain an average elevation of 7,800 ft., we must agree that the local moraines referred to, which come down to a level of 4,000 ft., betoken severe glacial conditions. According to Professor Penck, the snow-line at the time of their formation could not have exceeded 5,200 ft. in height. In other words, before the accumulation of the Hötting breccia the snow-line was depressed for at least 2,300 ft. below its present level. The ground-moraine which underlies the red breccia tells of a time when the Inn Valley was occupied by a vast glacier to which local ice-streams descended from all the lateral valleys and mountain-slopes.[1]

Let us now consider the character of the Hötting flora. The plants have been examined by Unger, Von Ettingshausen, and Stur, and more recently by Dr. R. von Wettstein. The latter has shown that certain leaves, which had been variously assigned by the former observers to the genera *Persea*, *Laurus*, *Laurinea*, *Quercus*, *Daphne*, and *Actinodaphne*, certainly belong to the living *Rhododendron ponticum*. This plant at the present day is a native of the mountain-regions south of the Black Sea. It is met with also in the Caucasus and in the hill-tracts in the extreme south of Spain. Von Wettstein observes that in the Pontic Mountains, at a height of 400 to 1,900 metres, this rhododendron is accompanied by an assemblage of plants similar to that with which it was formerly associated in the valley of the Inn. The flora includes the genera *Rhamnus*, *Acer*, *Fagus*, *Viburnum*, *Ilex*, *Carpinus*, *Pinus*, *Salix*, &c.—most of the plants being existing species. Some of the forms no longer flourish at such a

[1] I have been thus particular in my description of the superposition of the Hötting breccia because Professor Rothpletz in a recent work (*Ein geologischer Querschnitt dürch die Ost-Alpen*, &c., 1894) has endeavoured to show that the ground-moraine underlying the breccia has been forcibly intruded into that position. Unfortunately Rothpletz examined only one of the sections—of the existence of the others he does not seem to have been aware. The exposure visited by him is that which is seen above the Schloss Weiherburg. He says he could see no sandy layers in the ground-moraine, such as Penck has figured; the section, therefore, could not have been so clear as it was when the latter saw it, for the structure referred to came out well in a photograph. Rothpletz further says he could find no 'Urgebirgsgerölle' in the breccia. They are however, by no means of infrequent occurrence, and in the 'Höttinger Graben' they appear in large numbers. Rothpletz suggests that such 'erratics' might have been brought down from the Central Alps by the river itself, and that it is not necessary to suppose that they were carried by an old Inn glacier. But when we remember that they occur in the breccia up to a height of nearly 2,000 ft. above the river Inn, where the breccia also clearly overlies moraines, the most natural explanation is that they are true ice-borne erratics.

t above the sea, while others are not now natives of North . It is interesting to compare the mean annual temure of the regions to which the Rhododendron is indis with that of the Inn Valley. In the former the annual rature is 57° to 65° F., while at Innsbruck, 574 metres ft.) above the sea, it is only 47°. The Hötting flora, ver, flourished at an elevation of 1,100 to 1,200 metres to 3,937 ft.) in places where the mean annual temure does not now exceed 40°. We may reasonably infer, fore, that the climatic conditions of the Inn Valley were rly considerably more genial than at present. In short, e led to believe with Professor Penck that at the time Lötting flora clothed the slopes of the valley near Inns- the snow-fields and glaciers of the Alps must have d to the highest ridges of the mountains.

he Hötting breccia is overlaid by a second sheet of er-clay or bottom-moraine, in which fragments of the ia are included. Where this upper boulder-clay has removed, the rock shows a well-smoothed, polished and ed surface. The accumulation in question is the groundine of a much larger ice-flow than that which preceded ormation of the breccia. The former implies a snowt least 1,000 metres (3,281 ft.) lower than the present— atter, which rises to a greater height on the slopes of valley, indicates that the snow-line then stood at the evel of 1,400 metres (4,593 ft.) above the sea, or 1,200 es (3,937 ft.) below its existing level.[1]

'he deposits near Innsbruck thus tell the same tale as accumulations at Borlezza and Leffe. They supply us

[1] 'he height of the snow-line during glacial times is obtained by a very method. The first step is to ascertain the lowest parts of a glaciated from which independent glaciers have flowed. This gives the *maximum* of the old snow-line. Next, the lowest point reached by such glaciers is ained. It is obvious that the snow-line would occur higher up than that, a lower level than the actual source of the glaciers; and thus the *um* height of the former snow-line is approximately ascertained. The level from which independent glaciers formerly flowed, and the terminal reached by the highest-lying glaciers having been duly established, it is le to determine with sufficient accuracy the mean height of the old snow- See Professor Simony, *Mittheil. der k. k. geogr. Ges. in Wien*, 1872, p. 329; sor Höfer, *Sitzungsb. d. k. Akad. d. Wissensch., naturw. Classe*, Bd. lxxix. p. 331; Professor Partsch, *Die Gletscher der Vorzeit*, 1882; *Die tscherung des Riesengebirges zur Eiszeit*, 1894; Professor Penck, 'Geoische Wirkungen der Eiszeit,' *Verhandl. d. vierten deutschen Geographenzu München*, 1884.

with clear evidence of great climatic changes—changes which necessarily imply a long lapse of time. The glacial epoch which succeeded the genial interglacial conditions of the North Italian lignites and the Hötting breccia, was that during which the Alpine glaciers attained their greatest development. To give the reader some conception of the degree of glaciation to which the Alps were subjected at that time, I may shortly describe one or two of the better known of the old ice-flows. As mention has already been made of the great glacier of the Inn Valley, we may select it as a good type of other contemporaneous ice-flows.

The river Inn, as everyone knows, rises in the Silser See at the head of Upper Engadine, whence it holds a general north-easterly course till it joins the Danube. The Engadine is notable for the fact that it is nearly as wide towards its head as for many miles farther down. It is, in short, a broad depression or structural hollow that coincides in direction with the general trend of the main Alpine ranges. We reach the head of the gently-inclined valley, not in a narrow mountain-gully or in a cirque, but on the verge of a precipice that sinks abruptly into the deep Val Bregaglia. In short, the Engadine and the Val Bregaglia are simply different sections of one and the same great longitudinal hollow. There is thus no gathering-ground for snow on the watershed between these two valleys. And yet the Engadine was deeply filled with ice during the Glacial Period. The proofs of this are abundant. Ground-moraine covers the bottom of the valley in many places and is sprinkled here and there up to considerable heights upon the mountain-slopes.[1] Striated rocks and *roches moutonnées* also are frequently encountered all the way from the Maloja at the head of the valley down to its lower reaches. In Upper Engadine the mountain-slopes are severely glaciated up to a height of 2,000 ft. above the valley-bottom (5,700 ft., at least, above the sea)—the line separating the glaciated rocks below from the rough non-glaciated rocks above being particularly well-marked, while lateral moraines and erratics occur more or less abundantly at and below that level.

[1] I have seen it nestling in hollows up to a height of 1,950 ft., at least, above the valley-bottom.

The descent of the Engadine from the Maloja is very entle. To Campfer (seven miles) the fall does not exceed wenty-one feet, or three feet per mile ; while from the Maloja ɔ Celerina and Samaden, opposite the mouth of the Pontre-ina Valley, a distance of ten miles, the descent is 230 ft., or wenty-three feet per mile, and most of that fall takes place etween St. Moritz and Celerina. Now the trend of rock-triæ and *roches moutonnées* and the transport of erratics how clearly that the glacier which occupied the Engadine etween Celerina and Maloja flowed *up*, and not *down* the alley. The cause of this apparent anomaly is not far to seek. 'he Pontresina Valley, opening into the valley of the Inn rom the south-east, was gorged with ice, supplied chiefly by he Roseg and Morteratsch glaciers. This ice flowed into he Engadine nearly at right angles to the direction of that alley, and was deflected to left and right—one part making ;s escape up the Engadine, where it was joined by several ιteral glaciers, after which it poured across the watershed ιto the Val Bregaglia, and subsequently joined the great lacier that occupied the depression of Lake Como. The ther branch flowed down the Engadine in the direction of the ver Inn, through Tyrol, and eventually fanned out upon the ›w grounds of Bavaria, where it had a frontage of nearly ›rty miles—the terminal front extending thirty-eight miles eyond the mouth of the valley.

But the greatest of the ancient glaciers of the Alpine ɹands was that of the Rhone, a short account of which may ιot be without interest.[1] The present Rhone glacier is of nsignificant proportions, being hardly six miles in length. [ts source is surrounded by peaks and serrated ridges that rise to elevations of 10,500 to nearly 12,000 ft., and the glacier descends in a series of ice-cataracts to the level of 5,780 ft. above the sea. But at the climax of the Ice Age this glacier attained colossal dimensions—its upper limits and former extension having been mapped out for us by a

[1] The measurements of the Rhone glacier are taken chiefly from MM. Falsan's and Chantre's great work *Monographie géologique des anciens glaciers et du terrain erratique de la partie moyenne du bassin du Rhône*, 1880, t. ii. chap. xiv. See also Falsan's *Esquisse géologique du terrain erratique et des anciens glaciers de la région centrale du bassin du Rhône*, 1883 ; and *La période glaciaire*, 1889, chap. xv.

long line of eminent observers, among whom may be named MM. A. Favre, Gosset, Anselmier, Desor, Renevier, and others, who have traced the upper limits of the old glacier in Valais; and MM. Falsan, Chantre, and others, who have made known its further course and development in the low-grounds of France. At its origin, high on the flanks of the Schneestock, glaciated rocks go up to a height of 3,550 metres (11,647 ft.), thus showing that the upper surface of the ancient Rhone glacier at its source was more than 1,400 ft. higher than the surface of the existing glacier. Some sixteen miles farther down the valley, at Viesch, the upper limits of glaciation occur at a height of 1,680 metres (5,511 ft.), above the bottom of the Rhone valley. Opposite Leuk, twenty-five miles below Viesch, the surface of the glacier reached 1,500 metres (upwards of 4,900 ft.) above the present bed of the river; while at Martigny, thirty-five miles lower down the valley, glaciated rocks are met with at a height of 1,620 metres (5,315 ft.) above the Rhone. After leaving its mountain-valley this great glacier succeeded in drowning all the low-grounds of Switzerland. A wide *mer de glace* extended outwards from the Alps and abutted on the southern flanks of the Jura—only the higher ridges of which rose above the surface of the ice. Thus, on the slopes of Le Chasseron above Yverdon, at the head of Lake Neuchâtel, glaciated rocks occur at a height of 4,329 ft., that is, of 3,099 ft. above the level of Lake Geneva. If we add to this the depth of that depression, we get a thickness of over 4,000 ft. for the Rhone glacier in the low-grounds of Switzerland. The higher ridges of the Jura that overlook the Swiss Lowlands seem, in short, to have formed islets or *nunatakkr* in the great *mer de glace* which overflowed through passes in the mountains, reaching Ornans, some thirty miles north-west of Le Chasseron, and Salins, a similar distance in a westerly direction. Upon the southern flanks of the Jura we find numerous scattered blocks and boulders, all of which have been carried from the Alps across the intervening plains. Some of the blocks are of enormous dimensions: many contain thousands of cubic feet, and not a few are quite as big as cottages. Indeed one of them—the great granite-boulder of Steinhoff—might be compared, as Mr. Maclaren

as remarked, to 'a goodly-sized house of three storeys.' uch blocks have been observed on the Jura up nearly to the mits of glaciation; and from this elevation downwards they re strewn in greater or smaller numbers along the whole ountain-slope that faces the Alps.

The Jura Mountains formed an obstacle to the direct utflow of the *mer de glace* of the Rhone. Along the base f those mountains, therefore, the ice was deflected to right nd left. And here it is interesting to observe that we meet ith a true deflection-basin comparable to the rock-basins hich have been described in connection with the glacial henomena of Scotland. Lake Neuchâtel is obviously nalogous to the deep depressions which are so common a ature of the sea-floor along the inner margin of the ebrides. As it passed out of Switzerland the left or south ranch of the Rhone glacier was joined by the glacier of the rve and other ice-streams coming from the mountains of avoy, and flowed at first due south, being prevented llowing a westerly course by the opposing mass of the Grand olombier. On the flanks of this mountain, opposite Culoz, irty miles below Geneva, glaciation goes up to a height of 303 ft., so that here the ice was still not less than 3,150 ft. ick. Rounding the Grand Colombier the united ice-streams Rhone and Savoy, now joined by the glaciers of Dauphiny, nned out upon the low-grounds of France—showing a ontage that extended from Bourg, Trévoux, and Lyons to ienne, and thence by Beaurepaire to Vinay in the valley of e Isère—a distance of more than 100 miles.

It is interesting to note that between Culoz and Grenoble ll the hills under a height of 3,900 ft. are rounded and ice-orn, and sprinkled with ground-moraine. After crossing he secondary chain of the Grande Chartreuse and the Dent u Chat, the old *mer de glace* rapidly lowered its surface as t deployed upon the plains of Dauphiny and the Dombes.

In an earlier chapter (see p. 83) I have shown that the pper surface of the Scottish *mer de glace* sloped seawards vith a very gentle gradient. The upper surface of the Rhone glacier had a somewhat similar inclination. From its source in the névé-fields under the Schneestock to Oberwald, a distance of nine miles, the descent was steep,

for the bed of the valley between those two points has an average fall of probably not less than 700 ft. per mile. The slope of the surface of the ancient glacier in this steep part of its course was, therefore, some 300 ft. per mile. From Oberwald to Leuk, a distance of thirty-nine miles, the inclination of the valley-bottom is 59 ft. per mile—the surface-slope of the glacier was 75 ft. 8 ins. per mile. From Leuk to Martigny (thirty miles down the valley) the fall of the ground is 17 ft. 7 ins. per mile, while the inclination of the surface of the ice over the same section did not exceed 1 ft. 10 ins. This slight fall of the surface points to the gorging of the valley by the glaciers that flowed into it from the Central Chain of the Alps, and by the Aletsch glacier and other ice-streams coming from the opposite direction. Thus, between Brieg and Martigny there would appear to have been a certain stagnation of ice-flow. From Martigny north to the Lake of Geneva the surface-slope of the old glacier increased, for the ice had now room to spread out. Between Martigny and Culoz (100 miles or thereabout) there is a fall in the ground of 728 ft., say 7 ft. 3 ins. per mile. But between those places the surface-gradient of the Rhone glacier was nearly twenty-nine feet, or four times as great. After leaving Culoz the glacier crossed the Secondary Chain of the Alps to flow out upon the low-grounds—the slope of its surface between Culoz and Lyons being 42 ft. 5 ins. per mile.

Thus from its source on the Schneestock to its termination in the low-grounds of France, a distance of 245 miles, the average slope of the surface was 43 ft. 7 ins. per mile. It must be remembered, however, that the gradient in the upper reaches of the mountain-valley was very great. For purposes of comparison with the *mers de glace* of other regions it is better, therefore, to take the gradient of the ancient Rhone glacier between the head of Lake Geneva and the terminal moraines in the low-grounds of France. Over this part of its course the fall of the surface was 35 ft. 4 ins. per mile, a gradient closely approximating to that of the *mer de glace* that overflowed the Outer Hebrides (see p. 83).

It may be remembered that in the Midlands of England we encounter numerous erratics which could not have been

transported by glacier-ice at one and the same time—for they have been carried in different directions. The various lines of transport have crossed each other. The late Mr. Mackintosh pointed to the 'intercrossing of erratics' in England as showing that these boulders could not have been carried by land-ice, but were probably dropped by icebergs during an epoch of depression. Now, in the regions formerly traversed by the ancient Rhone glacier we meet with many examples of the same kind. Thus in the hills of Bugey and in the secondary mountain-chain of Savoy and Dauphiny there is abundant evidence to show that these heights have nourished independent snow-fields and glaciers of their own. For example, the old glacier of Valromey flowed from north to south for twenty miles down the valley of the Séran, which joins the Rhone a little below Culoz. Nevertheless, erratics of Alpine origin can be followed up the same valley for two-thirds of its length. Here, then, we have what appears to be conflicting evidence. The explanation, however, is obvious. Before the ancient glacier of the Rhone had reached the Secondary Chain of the Alps, the valleys in that region were occupied by local glaciers. Afterwards, however, when the Rhone glacier had united with that of the Arve, and this last with the glaciers of Annecy and Beaufort, and when these in like manner had become confluent with the great glacier of the Isère, the resulting *mer de glace* overflowed many of the foot-hills which had formerly supported independent snow-fields and ice-streams. Hence the morainic detritus of the Alps now overlies moraines of local origin. In other cases, where the secondary mountain-ranges were too lofty to be completely overwhelmed by the great *mer de glace*, long tongues of the latter were protruded into the valleys, and so compelled the local ice out of its normal course—sometimes, as in the case of the Valromey glacier, forcing it backwards up the valley down which it had formerly flowed.

The undercurrent and greater mass of the north branch of the Rhone glacier flowed north-east by Lake Neuchâtel along the flanks of the Jura—the upper strata of the ice streaming across that mountain-chain by various transverse valleys, as Birsthal and Frikthal. As the glacier made its

way towards the north-east it was joined successively by the glaciers of the Aar, the Reuss, and the Linth, and thereafter became confluent with the great glacier of the Rhine. How far down the valley of the Rhine this mighty *mer de glace* extended has not yet been determined. It became confluent with the glaciers of the Black Forest, and probably extended considerably farther; but the great valley is so deeply covered with fluvio-glacial and alluvial deposits that the utmost limits reached by the ice-flow have not been ascertained. We know, however, that the old glacier of the Rhine filled up Lake Constance, and extended north into the valley of the Danube for a distance of 50 miles beyond the northern shores of the lake. At the same time great glaciers descended by all the mountain-valleys draining towards the north, and these ice-flows become confluent on the low-grounds, so that the Alps were bordered by a continuous *mer de glace* that extended from the Rhine Valley through Baden, Hohenzollern, Württemberg, Swabia, and Upper Bavaria to the valley of the Salzach—a distance, not following all the sinuosities of the ice-front, of some 300 miles. To give some idea of the width attained by this belt of glacier-ice, it may be mentioned that the glacier of the Iller flowed north for twelve and a half miles beyond the foot of the Alps; that of the Isar for forty miles, and those of the Inn and the Salzach for thirty-eight and thirty-one miles respectively.

The ancient glaciers that descended from the Eastern Alps were on a much smaller scale than those I have just referred to, and did not flow beyond their mountain-valleys. And this is quite in keeping with existing conditions—the present snow-fields and glaciers of the Western Alps being considerably more extensive than those which appear towards the eastern end of the chain. The old glaciers of the Rhone, the Rhine, the Inn, &c., owed their larger development chiefly to the fact that they drained the loftier and wider mountain-region.

As in the north, so in the south the valleys of the Alps were filled with ice—the larger ice-flows escaping from their mountain-valleys to deploy upon the plains of the Po, for distances in some cases of fifteen to twenty-six miles from the foot of the mountains. These great lobes of ice, however,

id not as a rule become confluent on the low grounds. Thus he glaciers of the Tagliamento and the Brenta, and of Garda nd Iseo, as well as those of the Dora Baltea and the Dora tiparia, formed separate tongues of ice. It was otherwise, owever, with the ice-flows that occupied the drainage-area f Maggiore, Lugano, and Como. All these became confluent ipon the plains of Lombardy, with a united frontage some 36 miles in extent.[1]

I have dwelt so long upon the general aspects of the econd and greatest advance of the Alpine glaciers that it nay be well at this stage to remind the reader of the succes-ion of events, so far as we have followed it. First, then, it vill be remembered that the earliest glacial epoch was one of narked severity—the snow-line being depressed for 4,000 ft. r so below its present level. All the great mountain-valleys vere filled with ice—the glaciers flowing out upon the low-rounds, but not attaining the limits reached at the next cold poch. Then followed a great climatic change, when the ast snow-fields and glaciers disappeared, and the mountain-alleys were clothed and occupied by a flora and fauna indi-ative of genial conditions—conditions that were even more genial than are now met with in the Alpine Lands. Next upervened the second and greatest glacial epoch, of which I iave just been speaking.

[1] G. Omboni, *Atti d. Soc. Ital. d. Scienze nat. in Milano*, vol. iii.; A. Stoppani, *Geologia d'Italia, L'Era Neozoica*.

CHAPTER XXXIV.

GLACIAL PHENOMENA OF THE ALPINE LANDS—*continued.*

Interglacial and glacial deposits of Switzerland; —of the Iller valley, Bavaria; of Carinthia—Great breccias of Ramsau, &c.—Fluvio-glacial gravels; 'diluvial Nagelfluh' and plateau-gravels; high-terrace gravels; low-terrace gravels—Fluvio-glacial gravels, &c., of Lake Garda—Cemented gravels (Ceppo) of North Italy—Conglomerates at the foot of the Maritime Alps—Glacier-lake deposits of the Inn valley—Triple series of ground-moraines and fluvio-glacial gravels—Glacial succession in the Alpine Lands—Later moraines in Alpine valleys—Moraines of the 'first post-glacial stage'—Moraines of the 'second postglacial stage'—Correlation of glacial phenomena of Alpine Lands and Northern Europe—Lakes of the Alpine Lands; low-level and high-level lakes.

THE deposits that now fall to be considered are the lignites and associated alluvia of a second interglacial epoch.[1] These have been met with at a number of places in the Alpine Lands—the best known being the lignite-beds that occur in the neighbourhood of Zürich. At Utznach (at the head of Lake Zürich) and other places a leafy or laminated brown coal has been worked for many years. It consists of two layers separated by beds of gravel, sand, &c.—the whole being underlaid and overlaid by glacial accumulations. According to the late Professor Heer, these lignites represent the swampy shores of an interglacial lake, which, now and again

[1] The fossiliferous interglacial deposits of Switzerland appear to have been first recognised as such by E. Desor (1855), who saw that they could not be of preglacial age, as was formerly believed, since they rested upon an ice-worn surface. (*Revue des deux mondes*, 1875; *Le Paysage morainique*, p. 52.) Subsequently Messikommer pointed out that at Mörschweil and Unter-Wetzikon they were underlaid by glacial accumulations. (See Heer's *Urwelt der Schweiz*. 2te Aufl. p. 571.) The idea that the Swiss glacial formations are the product of two separate epochs of glaciation was set forth by A. Morlot in 1855 (*Bibliothèque univ. de Genève*; see also *Bull. de la Soc. Vaud. d. Sciences naturelles*, vi. 1857, p. 101); and by Scipion Gras in 1858 (*Archives de la Bibl. univ.* 1858, p. 5). These pioneers, however, were anticipated in their idea of two epochs of glaciation by Collomb, who in 1847 had published his evidence for two such epochs having occurred in the Vosges (see *ante*, p. 515). Collomb, therefore, would appear to have been the first to recognise the 'periodicity of glacial action.'

ıverflowing its limits, deposited sediment above the vegetable oil, and thus gave rise to alternating beds of peat and loam, and, gravel, &c. Among the plants recognised by Heer are he following :—*Pinus Abies* (common Swiss fir), *P. sylvestris* Scots fir), *P. montana*, *P. Larix* (larch), *Taxus baccata* (yew), *}etula alba* (birch), *Quercus robur* (oak), *Acer pseudo-plata-us* (sycamore), *Corylus avellana* (hazel), *Menyanthes trifo-iata* (bog-bean or marsh trefoil), *Phragmites communis* common reed), *Scirpus lacustris* (bulrush), *Rubus idæus* raspberry), *Polygonum hydropiper* ? (water-pepper), *Trapa ıatans* ? (water-chestnut), *Galium palustre* (marsh bedstraw), *Vaccinium vitis-idæa* ? (cranberry), *Holopleura victoria* (*helvetica*, Weber), an extinct form of water-lily, closely ıllied to if not identical with *H. holsatica* of the interglacial)eat of Schleswig-Holstein. Besides these, there are ,arious mosses and a horsetail reed. The osseous remains ıssociated with the lignite represent *Elephas antiquus*, *E. ›rimigenius*, *Rhinoceros Merckii*, Jæg., *Bos primigenius*, *Cervus alces*, *C. elaphus*, *Ursus spelæus*. In the same beds ccur numerous shells belonging to a few species, and bundant remains of beetles, &c.

The lignite-beds rest upon the accumulations of the pre-eding glacial epoch. When they were being accumulated, ıerefore, the great *mer de glace* had already disappeared from ıe low-grounds of Switzerland. The character of the organic ›mains, moreover, indicates a climate not less temperate than ıat which now obtains in the same neighbourhood. Hence e may reasonably infer that during the formation of the gnites the Alpine glaciers were not more extensively deve-ıped than they are at present. Again, as the lignite-beds are verlaid by morainic deposits, it is obvious that the Linth lacier once more occupied the depression of Lake Zürich—ı other words, there was a return of the excessive climate hat induced the earlier advance of that and other Alpine laciers. That these advances were really due to extreme limatic conditions is shown by the fact that it was only ınder such conditions, as Penck observes, that the Scan-linavian flora could have invaded the low-grounds of Europe and entered Switzerland. It is impossible, there-ore, that the interglacial flora could have flourished in

Switzerland while the immigration of northern plants was taking place.

Deposits of the same age as those of Utznach, Dürnten, &c., occur near St. Jacob, in the Birsthal, not far from Bâle. The beds consist of some 80 to 90 ft. of shingle and gravel, with an interstratified bed of clay, three feet thick, which has yielded plant-remains, such as pine, white birch, hazel, hornbeam, willows, cranberry, bog-whortleberry, bog-bean, privet, common dogwood, black alder, &c.—all being still indigenous to the low-grounds of Switzerland. The same bed has yielded many shells and a few insect-remains. From another bed of gravel in the same valley, which is a continuation of the upper gravel-beds of St. Jacob, Dr. Greppin has recorded the remains of the mammoth and the urus along with some land-shells. I may add that at Chambéry and Sonnaz in Savoy a bed of lignite with associated alluvial deposits occurs under a great thickness of glacial accumulations, and is believed to be of the same age as the interglacial lignites of Switzerland.

Similar peat- and lignite-beds are met with at other localities. Thus, in the railway-cutting at Kaibach, between Kissleg and Wangen in Upper Swabia, a bed of loam with overlying peat was disclosed resting on the hummocky surface of old morainic accumulations and covered by a mass of younger moraine. From these interglacial beds remains of mammoth and reindeer were obtained.[1] Still more interesting are the lignites that occur in the neighbourhood of Imberg, near Sonthofen in Bavaria. Here they have been followed along the hill-slopes of the Iller valley for more than a mile. The lignite is intercalated among beds of alpine gravel (cemented into conglomerate) which attain a thickness of 100 to 130 ft., and in places even of 200 ft., and are covered by great masses of moraine. Here and there the beds are cut through by side valleys, and are seen to rest upon true ground-moraine some thirty feet in thickness, but swelling out in places to 130 ft. The lignite does not sink to a lower level than 650 ft. above the Iller at Sonthofen. The vegetable-remains have not yet been fully studied, but they are composed chiefly of the trunks and branches of conifers which must have grown near where the lignites are found, that is, at a height of 3,000 ft.

[1] E. Fraas, *Scenerie der Alpen*, 1892, p. 305.

thereabout above the sea. It is incredible that coni-
'ous forests could have flourished at that elevation during
glacial epoch. A lowering of the mean annual tempera-
re by 3° C. only, as Dr. Penck has remarked, would render
e growth of trees at that height almost impossible, and
tainly would be insufficient to cause the glaciers of
gau to descend to the foot of the mountains, as we know
ey did, a distance of at least twenty-four miles. The lig-
es of Imberg, therefore, are evidence of a climate not less
nperate than the present. More than this, there is clear
of that the interglacial stage was of long duration, for it
ve the Iller time to effect very considerable erosion. The
cession of changes is thus summed up by Penck:—

1. The valley of the Iller is filled with a glacier which
ches the neighbourhood of Sonthofen—some 2,900 ft.
ove the sea. Low temperature.

2. The glacier retreats, and great sheets of gravel,
ching in places a thickness of 200 ft., are deposited.
mperature rising.

3. Vegetation extends over the gravel-terraces and flats,
d eventually forms two beds of lignite, about ten feet in
ckness. This accumulation of vegetable débris implies
e lapse of a long time. The lignites are then covered with
vel.

4. The valley of the Iller is next excavated to a depth of
0 to 720 ft. Temperature continuing relatively high.

5. A glacier again descends the valley. Renewed lower-
g of temperature.

Further east, at Kleinweil, near the Kochelsee, another
eresting interglacial lignite is seen. It extends south of
e river Loisach between the Kochelsee and the wide peat-
g of Eschenlohe, and attains in many places a thickness
six or seven feet. Its chief constituents are mosses, and
e compressed branches and stems of *Picea excelsa, Pinus
ntana*, and *Betula alba*. This lignite clearly rests upon
d is covered by true glacial accumulations. It gives us
glimpse of the conditions that obtained here and there in
e 'Vorland,' at the base of the Alps, during some stage
the second interglacial epoch—suggesting a marshy tract
ckly clothed with a woody vegetation, and indicating

climatic conditions approximately the same as those that obtain now in that region. These interglacial beds occur at a height of 1,970 ft. above the sea.[1]

It is unnecessary to describe every occurrence of interglacial lignite-beds in the Alpine Lands. Before leaving them, however, it may be noted that they all afford evidence of great interglacial and glacial erosion, as is shown by their appearance at levels high above the bottoms of the valleys. This is well seen at Utznach, for example, where, standing at the coal-mines, which are driven into the hill-slope, we look down into the valley at the head of Lake Zürich and see the terminal moraines, left during the retreat of the Linth glacier, forming heaps and ridges. The lignites and freshwater-beds evidently mark a much higher level of the lake, which must at one time have extended across the valley to a similar elevation on the opposite side, where, indeed, patches of the same freshwater-beds have been detected. Clearly, great valley-erosion followed their deposition—for the later moraines occupy hollows which have been excavated in an old interglacial land-surface. The deposits at Mörschweil, above the southern shore of Lake Constance, tell a similar tale.[2] It may be added that interglacial beds have been met with at some twenty different localities in the Alpine Lands. The last to which any particular reference may be made are those detected many years ago by Professor Höfer in Carinthia. In the lower reaches of the valleys of that region ground-moraine is well developed, and perched blocks and erratics are found at great elevations, while the glaciated aspect of the mountains further shows that the valleys at one time must have brimmed with ice. Overlying the ground-moraine come massive deposits of river-gravel, &c. (near Klagenfurt), which have yielded remains of the woolly rhinoceros, the steinbock (*Ibex cebennarum*), and *Bos taurus*. These freshwater-beds Professor Höfer correlates with the gravel-beds that immediately overlie the Dürnten lignites (corresponding to the *interglaciale Geröllbildung* of Heer). A younger series of large moraines met with in Carinthia

[1] A. Rothpletz, *Ein geologischer Querschnitt durch die Ost-Alpen*, &c., Stuttgart, 1894.

[2] They occur at a height of 230 ft. above the lake. (Penck, *Jahresbericht d. geograph. Ges. in München für* 1886, Heft ii.)

ıe Raiblersee, and in the Möll and Malnitzer Valley, ısiders to be the equivalents of the great moraines overlie the interglacial lignites of Switzerland.[1] ference has been made to the interglacial breccia of g. Similar ancient sheets of angular débris have been ith, under like conditions, in many other places. Al- ı these have not yielded fossils, their evidence yet adds :h to the conclusions arrived at as to the periodicity of ion. The breccias now referred to, which have been ›ed by Penck, Blaas, and Böhm, are all of local origin. ancient breccias rest in places upon ground-moraine, or ı striated erratics, and at the time of their formation, lleys could not have been occupied by glaciers at and the places where the consolidated débris-heaps are But the presence of superposed ground-moraines that after the subaërial accumulations had become ›r less firmly cemented, they were over-ridden by mas- aciers. Some of these breccias attain a very consider- ıickness. That of Ramsau (in the region of the old of the Enns) is described by Dr. Böhm as a true scree ;thalde), varying from 60 to 100 ft., and in places even ıg 160 ft. in thickness. Its upper surface is glaciated, ıgments of the breccia are included in the overlying l-moraine. This ancient scree has not been observed upon ground-moraine, but it contains scratched and ›d boulders, which could only have been derived from ›re-existing boulder-clay. It cloaks the lower slopes mountains,—sweeping downwards from a height of ;o 2,000 metres to the Ramsau plateau (1,100 metres) has been followed for a distance of about four and a iles. The formation of such a mass of débris by sub- weathering necessarily implies a long lapse of time.[2] re also I may refer to the occurrence of thick con- :ates, which in many places have been met with, oc- ıg an interglacial position. Those of the valley of the e were described long ago by Morlot,[3] who clearly re- ed their character, and similar interglacial gravels and

[1] *Neues Jahrb. für Min., Geol. und Pal.* 1873, p. 128.
[2] *Vergletscherung des Salzachgebietes*, Cap. vi.
[3] *Bull. de la Soc. Vaud. des Sc. nat.* t. vi. (1857) p. 101.

conglomerates have been described by Penck, Brückner, Blaas, Fugger, and others. As an example I may cite the conglomerate (*Nagelfluh*) which occurs in the neighbourhood of Salzburg. It forms a bed 170 ft. in thickness, composed of well-rolled stones arranged in horizontal layers, and has been followed in section for a distance of seven miles along the banks of the Salzach. It rests upon a ground-moraine containing the usual scratched erratics, and is overlaid by a similar glacial accumulation. Although this conglomerate includes no striated stones, there can be no doubt that it is of fluvio-glacial origin; but the total absence of such stones and the well-worn character of the gravel show that the deposit could not have been laid down immediately in front of a glacier. It is obvious, therefore, that before this fluvio-glacial gravel began to accumulate the glacier underneath which the lower ground-moraine was formed must have retreated. At a later date the glacier again advanced, as is shown by the presence of the superjacent ground-moraine. Now Professor Brückner has shown that the oscillation implied must on the lowest estimate have been considerable. Measuring from the most northern point at which the subjacent moraine is seen to the southern limits reached by the conglomerate, we have a distance of nine miles. This is the minimum distance, then, to which the glacier retired up the valley. But the moraine overlying the conglomerate shows that the ice-flow re-advanced for a distance of rather more than twenty miles. I need hardly say that Professor Brückner and the other glacialists who have described these conglomerates are quite aware of the fact that gravel-beds have also been formed underneath glaciers, but such subglacial gravels they have no difficulty in distinguishing from true fluviatile accumulations.

We have now learned that interglacial deposits occur on two separate and distinct horizons in the Alpine Lands. In other words, we have clear evidence of three glacial epochs, with two intervening epochs of genial conditions. Before advancing further it is necessary to direct attention to certain other phenomena which have a direct and important bearing upon the question of climatic oscillations. It has already been shown that fluvio-glacial gravels are invariably spread

ut in front of a glacier. If it be true, therefore, that three eparate ground-moraines occur in the Alpine Lands, we night well expect to encounter more or less well-preserved races of a similar succession of fluvio-glacial gravels. The arly researches of Morlot, Escher von der Linth, Mösch, ınd Mühlberg showed conclusively that in Switzerland these ravels (Alpine Diluvium) occurred on two horizons—each eries representing the fluviatile accumulations of a glacial poch. More recent research has confirmed the geologists f Switzerland in their interpretation of the evidence. They lo not doubt that there have been at least two great advances f the Alpine glaciers. The glacialists of North Germany re not more firmly convinced that the 'diluvial' accumuations of that wide region are divisible into a lower and an ıpper series, than Swiss geologists are that the equivalent leposits of the Alpine Lands may be similarly classified. 3ut in 1882 appeared Dr. A. Penck's remarkable work on the laciation of the German Alps,[1] in which he brought forward trong evidence to show that these mountain-lands had been laciated three times—each advance of the glaciers being reresented not only by ground-moraines, but by distinctive erraces of fluvio-glacial gravels. Geologists are very conserative, and if they had come to accept the view of a double laciation only after prolonged inquiry and discussion, it could ardly be expected that they should at once agree with Dr. 'enck in his conclusions. The elaborate work of Dr. Brücker on the glaciation of the Salzach region,[2] and the no less aborious investigation by Dr. Böhm of the accumulations ormed by the old glaciers of the Enns and the Steyr,[3] have ully confirmed Penck's general contention.[4] I may add that he same eminent observers, in company with Professor 'enck, have nearly completed an exhaustive survey of the Eastern Alps, of which they intend shortly to publish an

[1] *Die Vergletscherung der deutschen Alpen*, 1882. See also 'Ueber Periolicität der Thalbildung,' *Verh. d. Ges. für Erdkunde in Berlin*, 1884, No. 1; Mensch und Eiszeit,' *Archiv für Anthropologie*, Bd. xv. Heft 3.

[2] *Geographische Abhandlungen, herausgegeben von Prof. A. Penck*, Bd. i. Heft i.

[3] *Jahrb. der k. k. geol. Reichsanstalt*, 1885, Bd. xxxv. Heft 3, p. 429.

[4] See also Professor Blaas, 'Ueber die Glacialformation im Innthale,' *Zeitschr. d. Ferdinandeums*, iv. Folge, 29. Heft; 'Die alten Gletscher des tirolischen Innthal-Gebietes,' *Boten für Tirol und Vorarlberg*, 1886.

extended account. The results obtained by them are very interesting, and fully bear out the conclusions already arrived at from their explorations in the Bavarian Alps.[1] It is worthy of note also that a similar succession of glacial epochs has recently been determined by Dr. Du Pasquier in North Switzerland.[2]

As already remarked, an upper and a lower series of fluvio-glacial gravels have long been recognised in the Alpine Lands. But, as Dr. Penck has shown, the lower series is not, like the upper, the product of a single glaciation. He has proved that the lower gravels are divisible into two distinct series, which yield every evidence of having been laid down at widely separate epochs. The oldest gravel-beds are frequently cemented into conglomerate,—a consolidation accomplished before the deposition of the next succeeding fluvio-glacial accumulations. This is proved by the fact that boulders of the cemented gravel (Nagelfluh) occur in the later gravels. Not only so, but the Nagelfluh had previously experienced profound erosion, and in many places shows an ice-worn and striated surface underneath the later gravels. Another point is worthy of note. In some places where the Nagelfluh is directly overlaid by younger glacial gravels, its upper surface is more or less deeply weathered. Obviously it had been exposed for a prolonged period to the chemical action of rain, &c., for the rock is here and there 'piped,'[3] and covered with six or seven feet of disintegrated materials. This 'diluvial Nagelfluh' is not strongly developed in the mountain-regions, although now and again, as in the Inn Valley, it forms distinct terraces which rise above the levels reached by the later accumulations of fluvio-glacial origin. Upon the plateaux that sweep out from the base of the Alps, however, it occurs in massive sheets 160 ft. in thickness, which gradually thin away towards the north, until at a distance from the moun

[1] *Mittheil. des deutsch. und oesterreich. Alpenvereins*, 1890, No. 20 u. 23.

[2] *Beiträge z. geolog. Karte der Schweiz*, 31. Lief. 1891; *Archives d. Sciences phys. et nat.* 1891, p. 44.

[3] Rain water charged with acids from decaying organic matter eats into rocks that consist largely of calcareous materials. The carbonate of lime is dissolved out and carried away in solution—an action which takes place readily in the direction of cracks and crevices. The insoluble matter is left behind in the 'pipes' thus formed, and as these become widened and deepened, overlying superficial materials slowly subside into them.

ıs of nineteen miles the gravels do not exceed 80 to 100 ft. ;hickness, and by the time they have reached the Danube y have diminished to 30 or 50 ft. Evidently at one time se ancient gravel-beds formed a continuous sheet sweep- outwards from the mountains. They are thus termed :*kenschotter*, or, as I shall call them here, *plateau-gravels.* t long before the next succeeding gravels were deposited : diluvial Nagelfluh had been deeply trenched by streams, as to occupy more or less isolated positions, capping hills l ridges and elevated flats between contiguous valleys. us it can be shown that after the deposition of the Nagel- h and before the formation of the next succeeding fluvio- cial deposits the valley of the Inn was deepened to the ent of several hundred feet.

This remarkable conglomerate or Nagelfluh is composed stones derived from the valleys in which and opposite the uths of which it occurs. Not only so, but many of those nes have come from the Central Alps and occur in places which they could not have travelled by water. Thus, in the gelfluh of the Isar are many erratics which have travelled m the Central Alps across the mountain-ridges drained by t river. When these erratics entered the drainage-area :he Isar, the Inn Valley must have been filled with ice to rflowing—in short, their transport points to the invasion the Isar watershed by the *mer de glace* of a glacial ch. Yet another fact that leaves us in no doubt as to : origin of the 'diluvial Nagelfluh' :—the deposit contains -scratched stones, and is here and there interstratified with ıe ground-moraine. It is, therefore, a fluvio-glacial accumu- ion, and betokens a period of extensive glaciation, when : Alpine glaciers escaped from their mountain-valleys and ployed upon the low-grounds.

The deposition of the plateau-gravels was succeeded by a ıg period of valley-erosion. Alluvial accumulations were longer spread broadcast over the plateaux in front of : mountains. But streams and rivers cut deep and broad ırses through the plateau-gravels and the rocks upon which :se repose. A period of erosion thus followed a period of :umulation. In the deep and broad valleys so formed we counter a second series of gravel-deposits which occur at

very considerable heights above the present bottoms of the valleys. These form what are called the *high-terrace gravels*. The materials of which they are composed, although of the same character as those of the plateau-gravels, are upon the whole coarser. Here and there they are cemented into conglomerate, but this is much less frequently the case than with the older plateau-gravels. Like the latter, they occasionally contain scratched stones, and now and again are interstratified with morainic detritus. They are obviously connected with the terminal moraines of the outer zone—with those moraines that mark the greatest advance of the Alpine glaciers. That they are of fluvio-glacial origin, and were laid down during an advance of the great glaciers, there is not the least doubt. They betoken the presence of enormous flooded rivers—the water escaping from the glaciers being concentrated in valleys. The deposition of the plateau-gravels took place, it will be remembered, before the valleys that traverse the 'Vorland' had been excavated, and the flood-waters by which they were distributed were therefore less confined, and hence spread over wider areas.

Erelong this second epoch of accumulation passed away, and another protracted epoch of erosion supervened. So long a time elapsed that the high-terrace gravels were greatly denuded, and the valleys widened and deepened as before. The upper surface of the high-terrace gravels was also deeply weathered, and piped here and there to depths of three to ten feet.

Again, a third period of accumulation succeeded, and a new set of gravels, consisting of similar materials, was carried out from the Alps and spread over the valley-bottom, forming what are known as the *low-terrace gravels*. The connection of these gravels with the youngest terminal moraines (moraines of the inner zone) is everywhere apparent. Obviously they bear to these moraines the same relation that the high-terrace gravels bear to the moraines of the outer zone:—they are of fluvio-glacial origin. Since the time of their deposition the streams and rivers have again deepened and widened their valleys, so that the upper surface of the low-terrace gravels is now far beyond the reach of the greatest river-floods of our day.

This threefold development of fluvio-glacial gravels which Penck established for Upper Bavaria has now been found to hold good for all the Alpine 'Vorland' between the Rhine and the Traun.[1] Each series of gravels, as we have seen, is associated on the low-grounds with contemporaneous terminal moraines. Of these latter the most perfectly preserved, as might have been expected, are those of the third glacial epoch. The moraines of the outer zone, which mark the limits reached by the Alpine glaciers at the period of their greatest extension, are often highly weathered and denuded, and more or less concealed under sheets of younger fluvio-glacial and alluvial deposits. The moraines with which the earlier plateau-gravels are connected are less well-preserved and more deeply weathered than those of the second and third glacial epochs. And this, too, we might well have expected, for their greater age alone must have insured for them more extensive denudation than the others have experienced. It must also be borne in mind that they lie nearer to the mountains than those of the second and third glacial epochs, and have thus been twice over-ridden by glaciers. Hence they are much less prominent than the later moraines. Nevertheless they have been traced in various regions. Thus they have been followed from the valley of the Thur across the lower reaches of Lake Constance, whence they swing round the heights (Göhren Berg, &c.) that lie west of Ravensburg. They have also been tracked from the valley of the Iller, by Lake Ammer and Lake Würm to the valley of the Isar, and they occur likewise between Lake Chiem and the Salzach, a tributary of the Inn.

A similar triple series has been observed by Professor Penck on the south-west shores of Lake Garda, where the fluvio-glacial gravels and moraines of three distinct epochs of glaciation can be seen. Each ground-moraine is much weathered atop and separated from the one resting upon it by a loam of weathered materials (Verwitterungslehm). This, it may be added, is much thicker than the similar loam that cloaks the upper surface of the youngest moraine of the

[1] The threefold development of moraines and fluvio-glacial gravels can be very conveniently studied in the 'Vorland' of Upper Swabia, in the neighbourhood of Lake Constance. See *Bericht über die Excursion nach Ober-Schwaben und dem Bodensee des X. deutschen Geographentages in Stuttgart*, 1893.

series; from which Penck infers that the interglacial epochs were each of longer duration than the time which has elapsed since the accumulation of the latest moraine.[1]

The 'diluvial Nagelfluh,' which is so well developed along the north front of the Alps, appears to be represented on the south side of the chain by similar cemented fluvio-glacial gravels, which are well-known to the geologists of Italy as 'Ceppo,' and assigned by them to the Pliocene system. Having studied this Ceppo in North Italy, I long ago formed the opinion that it was precisely of the same character and origin as the fluvio-glacial gravels of the northern Alpine Lands.[2] Like the plateau-gravels of Upper Swabia and Upper Bavaria, it bears everywhere the marks of great age, and had been extensively eroded and denuded before the large moraines opposite the mouths of the Alpine valleys had been heaped up. These moraines, which are so fresh and well-preserved, belong doubtless to the last great extension of the Alpine glaciers. They represent, according to Professor Penck, the latest moraines of the inner zone as already described. South of Lake Garda my friend has been able to trace out a triple series of moraines, but no moraines, corresponding to those of the outer zone of the northern Alpine Lands, have been detected elsewhere in Northern Italy. The presence, however, of the highly denuded 'Ceppo' underlying the great terminal moraines of Ivræa, Como, &c., shows that these latter cannot be the product of the second and greatest extension of the Alpine glaciers. The frontal moraines of that epoch have disappeared—just as those of the ancient Rhone glacier have to a large extent vanished from the plains of France—having been ploughed down by streams and rivers, or buried under alluvial accumulations.[3]

[1] 'Die grosse Eiszeit,' *Himmel und Erde*, 1892. A. Negri finds evidence [in] the 'morainic amphitheatre' of Astico of two glaciations. *Atti R. Istit. Vene[to] di Sc., Lett. ed Arti*, 1887.

[2] *Prehistoric Europe*, p. 316.

[3] It may be noted here that M. Delafond recognises in the valley of the Rhone, in the neighbourhood of Lyons, three separate and distinct accumula[-]tions of fluviatile gravels, which appear to be of fluvio-glacial origin. The oldest set of gravels belongs to the geological horizon of *Elephas meridionalis*, while in the other two occur the remains of *Elephas primigenius*. A loam with *E. intermedius* overlies the morainic accumulations of the district (*Bull. des Services de la Carte géol. de la France*, 1889, No. 2.) Professor Pantanelli

In connection with the 'Nagelfluh' of the north and the 'Ceppo' of Italy, I would call attention to the remarkable conglomerates which overspread the foot-slopes and coast-lands of the Maritime Alps. They are very well-developed in the neighbourhood of Nice, where they have been studied by the late M. E. Desor.[1] They form massive accumulations in the valleys of the Var, the Roya, the Arosia, &c., where they reach a thickness of at least 600 ft. The stones are well rounded and from about the size of a walnut to that of the fist in size—blocks as large as the head being rather exceptional. They have all been derived from rocks within the drainage areas of the valleys in which the conglomerates occur. The most remarkable feature of the deposits is the steep inclination of the bedding, which varies from 12° or 18° to 20° or 25°, and here and there, as in the valley of the Arosia, to as much as 40° to 50°. This high angle is the more noteworthy since the Pliocene sands and clays on which the conglomerates repose are approximately horizontal. The latter, it may be added, go up to a height of 1,300 ft. above the sea, and are evidently of relatively great age, since they have been everywhere profoundly eroded by streams and rivers. They are usually quite unfossiliferous, but in a thin layer of sandy clay, near the base of the deposits, M. Desor obtained a few shells (*Ringicula*), a heart-urchin (*Brissopsis lyrifera* ?), and the impression of a leaf closely resembling that of the evergreen oak, which is a common tree on the Ligurian coast. According to Desor, this massive conglomerate is of torrential origin, and was laid down in the sea at a time when the valleys in which it occurs were narrow fiords. It is overlaid by some thirty feet of calcareous marls and travertine, which have yielded marine shells in places. Long after the conglomerates and travertine had been elevated above the sea-level and profoundly eroded, another series of gravels (frequently cemented into con-

has described the occurrence of similar successive river-terraces in the great plains of the Po. Thus in Emilia three such terraces may be followed—the highest rising, as we ascend the valley from the sea to Piacenza, from 150 metres to 300 metres, the middle one from 100 metres to 200 metres, the lowest and youngest considerably below the preceding. (*I Terreni quadernari e recenti dell' Emilia*. Modena, 1893.)

[1] *Bull. Soc. Niçoise des Sci. nat. et hist.* 1879, p. 137. *Sur les Deltas torrentiels anciens et modernes* (Lettre à M. A. Falsan). Nice, 1880.

glomerate) were swept down from the Alps and deposited upon the much-denuded surface of the 'conglomérat ligure.' These gravels with certain overlying loams are assigned by Desor to the Quaternary or Pleistocene period. The great thickness attained by the older conglomerates, and the high pitch of their bedding, unquestionably point to the long-continued flow of torrential rivers. The deposits in question are not apparently connected with moraines, after the manner of the Nagelfluh, but we may well suppose that the torrential waters to which they owe their origin were derived from more abundant snowfields than are now met with in the Maritime Alps.[1] Their evidence, in short, is in keeping with that supplied by the 'Ceppo' of North Italy and the 'diluvial Nagelfluh' of Upper Swabia and Bavaria.

The several series of fluvio-glacial gravels developed upon the Alpine 'Vorland' can hardly be identified in the mountain-valleys. In those regions deposits of the kind, owing, partly to the steeper gradients of the ground, could not be accumulated to the same extent, and were liable to be ploughed up and incorporated in the ground-moraines of the advancing glaciers. Such ground-moraines, therefore, frequently rest upon the solid rock-bottoms of the valleys. It is only when the glaciers deployed upon the low grounds, and were nearing the end of their journey, that fluvio-glacial gravels were likely to be preserved and covered over with ground-moraine. Nevertheless, even in the mountain-valleys bedded accumulations of gravel, sand, and clay now and again attain a very considerable thickness underneath ground-moraines. Such, for example, is the case in the great valley of the Inn, where the deposits in question form a well-marked terrace, as in the neighbourhood of Innsbruck. The sporadic appearance of such aqueous deposits in the mountain-valleys—their abundant development in some regions, and their entire absence from other places apparently similarly situated—has puzzled geologists. But recent researches by Professors Penck, Blaas, and others have shown that the deposits in question have been accumulated in glacier-lakes. Such lakes

[1] Desor has described the occurrence of morainic accumulations in the same region. The Pleistocene loams and conglomerate he believed had been laid down by torrents escaping from the old glaciers.

ppear to have been formed both during the advance and the etreat of the glaciers.[1] As the glaciers advanced it is obvious hat all the valleys could not be occupied from end to end at ne and the same time. A glacier descending a main valley nust not infrequently have traversed the mouths of tributary alleys before their ice-streams had advanced so far. Hence he lower reaches of such tributaries would be occupied by lacier-lakes. In other cases, as in that of the Inn, the laciers of large tributary valleys deployed upon the great alley long before the main glacier had been fully developed. Thus the glacier of the Ziller Valley formed an ice-dam across he Inn at Jenbach, above which appeared a lake that xtended as far as Mötz, below the mouth of the Oetz Valley, a istance of thirty-seven miles. In this lake were accumulated heets of gravel, sand, and silt which now form in places subor- inate terraces. Below the mouth of the Ziller Valley such erraces are not met with in the Inn Valley, but are seen in he lower reaches of some of its tributaries. When at last the whole valley of the Inn became filled with ice, the lacustrine leposits were ploughed into and covered over with ground- noraine. Similar phenomena have been met with by Pro- essors Penck, Brückner, and Böhm, throughout the whole extent of the Eastern Alps.[2]

My limits will not allow me to enter into further detail, out enough probably has been advanced to show that the evidence furnished by the glacial and interglacial deposits of the mountain-valleys is on all-fours with that which has been gathered from the low-grounds that sweep out from the base of the Alps. The former we find have experienced three uccessive glaciations, each of great severity—the second having been the most intense. An epoch of genial conditions eparated the first from the second glacial stage, and a similar pell of mild climate supervened between the second and hird cold epochs. Those interglacial epochs were of long luration. This is shown by the character of their flora— mplying as it does climatic conditions not less temperate

[1] See Blaas, *Jahrb. d. k. k. geol. Reichsanstalt*, 1889, Bd. xxxix. p. 480.

[2] Penck, 'Die Glacialschotter in den Ostalpen,' *Vortrag gehalten in d. S. Breslau des deutsch. u. österreich. Alpenvereins*, October 18, 1890. The same aper contains a short abstract of the forthcoming work on the glaciation of the Eastern Alps by Penck, Brückner, and Böhm.

than those of our own day. The dissolution of the mighty glaciers, however rapidly effected, could not have been sudden. The disappearance of the Alpine *mers de glace* and the subsequent immigration of an interglacial flora must, in a word, have covered a period of protracted duration. And the same conclusion may be drawn from the amount of erosion which the rivers were able to accomplish during interglacial times. How closely in keeping with all this is the evidence supplied by the glacial and fluvio-glacial accumulations of the Alpine ‘Vorland’! Each series of fluvio-glacial gravels is connected with a series of terminal moraines. The ‘plateau-gravels’ were spread broadcast over the low-grounds before the present broad valleys had come into existence. The next succeeding, or ‘high-terrace’ series, was deposited within those valleys after they had been eroded to a considerable depth. Subsequently the rivers worked their way down through those gravels, and lowered the bottoms of the valleys, after which the ‘low-terrace’ gravels were heaped up. Long periods of valley-erosion thus separated the epochs during which the fluvio-glacial deposits were accumulated. Each line of terminal moraines, as we have seen, marks the farthest limits reached by the glaciers. The moraines of the first glacial epoch lie nearest to the mountains—those of the second epoch occur at the greatest distance from the base of the Alps, while the third and latest moraines occupy an intermediate position.

So far as we have gone, then, it is obvious that the glacial succession in the Alpine Lands is comparable to that of Northern Europe. The earliest recognisable glaciation of the Alps is represented by the arctic marine beds of the Upper Pliocene in Britain, and by the ground-moraine of the oldest Baltic glacier. The greatest advance of the Alpine glaciers, again, corresponds to the vast ice-sheet of the ‘lower boulder-clay’ of Northern Europe, while the latest terminal moraines in the Alpine ‘Vorland’ are equivalent to the ‘upper boulder-clay’ of Britain and the ‘ober Geschiebelehm’ that advances south beyond the valley of the Elbe in North Germany.

We have next to inquire whether in the Alps there are any morainic accumulations which can reasonably be assigned to the horizon of the last great Baltic glacier and the district

ice-flows of the British Islands. And further, we have to ask whether in the higher Alpine valleys there be any evidence of an advance of the glaciers comparable to that which took place in Scotland after the formation of the so-called 'postglacial' raised beaches.

When we leave the conspicuous terminal moraines of the inner zone—those, namely, which mark the limits reached by the great glaciers of the third cold epoch—and advance into the mountain-valleys, we meet with no similar end-moraines for a long distance. This remarkable absence of 'moraines of retreat' was particularly noted by Penck during his investigations in North Tyrol, and the same fact has been recorded by Brückner with regard to the Salzach region, and by Böhm in connection with the glacial phenomena of the Austrian Alps. It is only after we have penetrated far into the mountain-regions that conspicuous end-moraines again put in an appearance. Brückner has given an interesting account of the glaciation of the Julian Alps,[1] from which we learn that the terminal moraines of the third epoch are conspicuously displayed in the valleys of the Save and the Isonzo. Not until the upper reaches of those valleys are approached, however, do end-moraines again appear. And these are so fresh and well-preserved that Brückner is of opinion that they must have been heaped up at a period long subsequent to the retirement of the great glaciers from the low-grounds. The latter would seem to have melted away continuously, making no pauses, so that their retirement was not marked by the accumulation of conspicuous end-moraines. Of course it may be held that the recent-looking end-moraines simply mark a stage in that retreat, but Brückner maintains, with some reserve, that this is not the case. He thinks it more probable that the moraines in question were deposited during an advance of the glaciers long subsequent to the disappearance of their mighty predecessors. It is pointed out that these glaciers obviously formed a harmonious system. Each attained the dimensions which its surroundings had determined. Those that originated in the wide névé-fields of the high plateaux

[1] 'Eiszeit-Studien in den südöstlichen Alpen,' *X. Jahresb. d. geograph. Ges. v. Bern*, 1891.

naturally attained the greatest bulk and flowed to the lowest levels, while those whose feeding-grounds were of limited extent had but a short course, and terminated at the highest levels. Again, the glaciers that descended from the most elevated ridges, where no wide plateaux exist, came to an end midway between those two extremes. In a word, each individual ice-flow stood in obvious relation to its surroundings and to the position of the snow-line, which at the period in question occurred at a height of 1,700 metres (5,578 ft.), or 900 metres (2,953 ft.) lower than at present.

Professor Penck has kindly sent me a map of the Alpine Lands, upon which he has marked the positions occupied by the terminal moraines in the mountain-valleys, as observed by himself and others. All these are described as of postglacial age, in the sense that they are later than the third and last general glaciation of the Alps, when moraines were deposited upon the low-grounds at the foot of the mountains. The valley-moraines in question represent two distinct stages—the older series being well-developed in the main valleys and indicating a glaciation considerably less excessive than that of the third glacial epoch, but one, nevertheless, of great severity. The younger moraines, on the other hand, occur towards the heads of the higher valleys, and testify to less severe glacial conditions. As these 'postglacial moraines' will be described by my friend and his colleagues Professor Brückner and Dr. Böhm in their forthcoming work on the 'Glaciation of the Eastern Alps,' I shall do no more than cite one or two examples in illustration of the relative positions occupied by the two series.

I have already mentioned the fact that the so-called 'postglacial' moraines occur in the mountain-valleys often at very considerable distances above those of the third glacial epoch. Thus the first postglacial moraines of the Rhine Valley are met with near Chur—some eighty-five miles above the limits reached by the third great *mer de glace* that invaded Upper Swabia. In the valley of the Isar the distance between the moraines of the 'inner zone' (*i.e.* those of the third glacial epoch) and the oldest postglacial moraines is upwards of forty miles. In the valley of the Salzach the latter occur at a distance of fifty miles above the former, and

e drainage area of the Drave the distance between the is about the same. Once more, the earliest 'postglacial' ιines occurring in the valley of the Adige are eighty-five s above those at the lower end of Lake Garda. The tglacial' glacier of the Inn may be cited as a good ıple of its kind. After leaving the moraines of the r zone we do not encounter the moraines of the first glacial stage until we are well into the mountains. They ar a little below the opening of the Zillerthal, or sixty s above those of the inner zone. Their presence at this t indicates a glacier of no mean dimensions. It has dy been mentioned that during the climax of the Ice the glacier that occupied the upper valley of the Inn was cted opposite the mouth of the Pontresina Valley to left right. Now the same appears to have been the case ıg the first 'postglacial' stage—the left or south-west ch of the glacier flowing up the valley and across the)ja into Italy, while the right or north-east branch made 'ay down the Inn Valley as far as the Zillerthal. Thus 'postglacial' ice-stream, measured from the ice-shed Lago Nero, at the head of the Pontresina Valley, was ess than 125 miles in length.

.fter leaving the moraines of the 'first postglacial stage' her terminal moraines are seen in the main valleys. It ıly when we advance up some of the lateral valleys ιing the Central Alps that we meet with the second s of 'postglacial' moraines. Thus they are well-loped in the higher valleys of Tyrol, as in the Oetzthal, ıe Geschnitzthal (a side-valley of the Wippthal),[1] and ıe Zillerthal. They occur also in the valleys of the tian and the Bernina Alps that drain into the Inn. As ıples may be cited the moraines at the foot of Val Minor Val del Fain near the Bernina Pass, those of the Roseg ɛy and the valley above Pontresina, and the well-marked ıds at the mouth of the Val Muretto near Maloja.

[ow while it is possible that each of these conspicuous .inic stages may represent pauses in the retreat of the

[1] r. F. Kerner v. Marilaun, *Mittheil. d. k. k. geograph. Ges. Wien*, 1890, ; *Sitzungsber. d. kais. Akad. d. Wissensch. in Wien* (math.-naturw.). Bd. C. Abth. i. 1891.

great glaciers of the third glacial epoch, they more probably indicate two successive advances in times long subsequent to the disappearance of those great glaciers. The phenomena described by Dr. Brückner in connection with the moraines of the Julian Alps strongly favour the latter interpretation of the evidence. It is particularly noteworthy that the younger 'postglacial moraines' do not appear in the valleys of the Eastern Alps, but seem to be confined exclusively to the higher valleys of the Central range. Thus in the Salzburg Alps, the Salzkammergut, and the Julian Alps the only postglacial moraines met with are those of the older series, while in the ranges lying farther east neither the younger nor the older postglacial series occurs—the only moraines in those regions belonging to the Glacial Period proper. But both 'postglacial stages' are seen in the valleys that head in the elevated Central Alps. So clearly has this succession been made out for the ranges extending from the Rhætian Alps to the eastern end of the great chain, that we can hardly doubt that a similar succession will erelong be established for the western section of the Alpine Lands. But those geologists who have such objections to a threefold glaciation of these lands will probably prefer to believe that the later moraines, described by Penck and his colleagues as 'postglacial,' merely mark separate stages in the retreat of the *mer de glace* of the third glacial epoch. As we have already seen, however, the third glacial epoch of Northern Europe (that of the upper boulder-clay of Britain and the 'ober Geschiebelehm' of the valley of the Elbe, &c.) was followed, after a prolonged interglacial epoch, by the appearance of large district-glaciers and *mers de glace* in our islands and by the advent of the last great Baltic glacier. And further, as we have learned, the district-glaciers of our islands were succeeded by another long epoch of genial conditions, after which local glaciers again appeared in our mountain-glens, and here and there descended to the sea-coast. It is impossible to believe that the climatic changes referred to could have been confined to our latitude. They must of necessity have affected a much wider area. It seems in the highest degree probable, therefore, that the so-called 'postglacial moraines' of the Alps are indicative of two successive

ıdvances of the glaciers, each separated from the other and rom the preceding third glacial epoch by more or less pro-onged interglacial stages.[1]

Hitherto no representatives of the highest-level corrie-akes and moraines of the Scottish Highlands have been ecognised in the Alps—no third postglacial 'stadium' has een noted. But I would point out that the loftier moun-ain-ranges of the Western Alps have still to be critically xamined. It is there, if anywhere, that we may expect to neet with a younger series of moraines than those of the so-alled 'second postglacial stage.'

Before we take leave of the Alpine Lands it may be well o glance, however briefly, at the peculiar distribution of heir lakes, and to note how closely these are connected with he development of glacial phenomena. We remark, in the irst place, that there are two regions in which lakes are eculiarly prominent. All the larger lakes appear at or near he lower ends of the great valleys, and are thus, roughly peaking, distributed round the margins of the mountain-egions, while an abundant series of smaller lakes occurs owards the heads of the loftier mountain-valleys. We have hus two zones—one of large low-level lakes, and another of mall high-level lakes.

The low-level lakes, we observe, lie wholly in the peripheral r marginal areas occupied by glacial deposits, and it is re-narkable that their dimensions are proportionate to the size f the great ice-flows which formerly occupied them. That hey are closely connected in origin with the ancient glaciers s sufficiently shown by this fact. Thus in regions where the laciers escaped from the mountains and flowed well out upon he forelands, as in North Switzerland and Upper Bavaria, he lakes occur beyond the mouths of the mountain-valleys. n North Italy the great lakes lie partly in the mountain-alleys, partly in the low-grounds—and the position of large noraines at their lower ends shows that the ice-front ex-

[1] I ought to mention here that my friend Prof. Penck also holds the view hat the first postglacial stage of glaciation in the Alps is on the same horizon s the last great Baltic glacier and the district ice-sheets and large valley-laciers of Britain. His second 'postglaciales stadium' he correlates, as I do, with the small local glaciers which in our NW. Highlands descended to the ea during the formation of our 50-ft. beach.

tended no farther. Once more, in districts where the old glaciers were wholly confined to the mountain-valleys the lakes are similarly situated, as in the Salzkammergut and in Carinthia. Dr. Böhm, who calls attention to these facts,[1] points out that lakes do not always occur at the lower ends of the beds of former glaciers. They do not appear, for example, in the valleys of the Lech, the Inn, the Salzach, the Steyr, the Enns, and the Mur—in all those regions basins at one time existed, but they are now filled with alluvium. The same writer remarks that the surface-slope of the old glaciers must have increased as they escaped from the mountain-valleys, and this increase of slope would be accompanied by quickened movement, and consequently more active erosion. But motion and erosion would gradually diminish with the attenuation of the glaciers, until at last they were reduced to zero. Dr. Böhm further points out that the depth of the large lakes is not only proportionate to the size and surface-slope of the ancient glaciers, but also to their proximity to the mountains. The great lakes of Lombardy, for example, which attain depths of 900 to 1,300 ft., occur just where the beds of the old glaciers suddenly flattened out as the lower ends of the mountain-valleys were reached. It was precisely there, however, where the slope of the upper surface and the motion and erosive action of the glaciers were increased. In Switzerland the lakes that are similarly situated reach depths of 650 and 1,000 ft., while those of the mountain-valleys of Upper Bavaria and Austria do not exceed 300 to 650 ft. On the other hand, the lakes of the Swiss 'Vorland' attain depths of nearly 500 ft., while in similar positions in Upper Bavaria the lakes are not deeper than 350 ft. Great as some of these depths are, they are small in proportion to the size of the lakes. Thus the depth of Lake Como is only 130th part of its length, while Lake Würm, the Lake of Geneva, and Lake Garda, are respectively 180, 230, and 280 times longer than they are deep. These lakes, therefore, like the corresponding lakes of Scotland, occupy relatively shallow troughs. Were the water drained away, we could not in many cases,

[1] 'Bodengestaltende Wirkungen der Eiszeit,' *Vortrag gehalten in der Breslau des deutsch. u. oesterreich. Alpenvereins*, 1891, p. 498. See also the same author's most instructive paper on the old glaciers of the Enns and Steyr: *Jahrb. d. k. k. geol. Reichsanst.* 1885, p. 523.

thout careful measurement, discover the basin-shaped aracter of the exposed bottoms.

Some of the large lakes come under the category of eflection-basins,' such as Lake Neuchâtel and the Lake of enne, while the Lake of Geneva is partly a valley-basin d partly a deflection-basin.[1] The upper portion, which merly extended up the valley of the Rhone as far as Bex, comparable to one of the lakes of Lombardy; the northern lf, like the basin of Lake Neuchâtel, owes its origin to the osive action of the great Rhone glacier, which was deflected right and left by the Jura Mountains.

Leaving the peripheral areas of the Alpine glacial deposits d advancing into the mountains, we are surprised to find w or no lakes at all in the main valleys. It is only when e more elevated mountain-tracts are reached that lakes, ostly very small, are encountered in the high valleys and cirques. Numerous as these still are, they were formerly ore so, for not a few have been silted up or tapped and ained by the out-flowing streams. Böhm tells us that any have disappeared within recent times. A comparison old and recent maps of Tyrol shows that within the last ndred years no fewer than 118 lakelets have vanished from at region alone. How many, therefore, must have vanished om the Alpine Lands since the last retreat of the glaciers. aces of them are seen in very many valleys—the basins ing in some places occupied by peat-bogs—in other places ed up with alluvial detritus or drained by the lowering of eir outlets. It seems probable, as Böhm remarks, that any of the larger valleys of the Alps may have contained ains of lakes connected by short courses of swift-flowing eams and rapids, such as are to be seen in not a few moun-in-valleys in Norway and Sweden. So long a time has apsed, however, since the final retreat of the great Alpine aciers, that the shallow valley-lakes referred to have nearly l disappeared. That so many lakes should still exist in the eripheral areas is accounted for by their greater depth—the allow ones have been silted up, the deeper ones endure.

The high-level lakes, notwithstanding their small size, e still numerous, for the glaciers to which they owe their

[1] Penck, *Die Vergletscherung der deutschen Alpen*, p. 400.

origin vanished at a relatively recent geological period. Running water has not yet had time to obliterate them. They are most plentiful in the immediate neighbourhood of the glaciers, or in the highest valleys and cirques of regions where no glaciers now exist, while in non-glaciated mountain-tracts they do not occur. Most frequently they are shallow, two or three yards or so in depth : occasionally, however, they may be thirty feet up to a hundred feet or more. They are also, as a rule, of small size, seldom reaching a fraction of a mile in diameter, while a few are rather more than a mile across. They are thus relatively deeper than the large lakes of the peripheral regions, and bear witness, as Böhm remarks, to an erosion more energetic and concentrated than that to which these last owe their origin. The glacial appearances with which they are associated are usually wonderfully fresh. Highly polished *roches moutonnées* often appear as islets, while the sides and lips of the basins are similarly smoothed and striated. All the high-level lakes of the Alps, however, do not occupy rock-basins. Many, as in our own country, are dammed up by rock-falls, or by torrential deposits or moraines, while others simply fill hollows in the surface of glacial accumulations. The great majority, however, lie in 'Karen,' or modified cirques, and are thus of the same character as the Corrie-lakes of Scotland. The process by which they are tapped and drained by running water is graphically described by Dr. Böhm. The water begins its work as a cascade pouring over the lip of the basin, but gradually gnaws out for itself a gorge which it will eventually cut back into the heart of the cirque. Thus erelong the basin will be drained, and in time all the characteristic features of the glacially-modified cirque must disappear, and the valley-head will then resume the aspect of an inverted hollow cone or funnel.

Now the high-level lakes form harmonious systems in the various mountain-groups in which they occur—they obviously speak to the former presence of local glaciers, each of which attained the dimensions determined for it by the height of the snow-line and the form of the mountains. Dr. Böhm tells us that in the Rhætian Alps 70 per cent. of all the mountain-lakes occur between 2,200 and 2,800 metres

ove the sea; in the Hohe Tauern 85 per cent. range from 000 to 2,600 metres; in the Niedere Tauern 87 per cent. e met with between 1,700 and 2,300 metres; in the Noric ps 68 per cent. occur between 1,600 and 2,100 metres; ile in North Tyrol and the Salzburg Alps, as also in the lian Alps, the lake-level lies between 1,300 and 1,900 metres. is obvious that all these groups of lakes did not originate the same time. Those at the lower levels, as in the Niere Tauern, the Noric Alps, the Julian Alps, the Salzburg ps, and North Tyrol, are of greater age than the others. heir basins must have been excavated at a time when all e valleys draining the Central Alps were occupied by aciers, which descended the main valleys often for considerle distances. The terminal moraines that occur at the wer ends of the lakes in question belong, in short, to the irst postglacial stage.' Thus the small local glaciers of the lian Alps, &c., were contemporaneous with the much larger e-stream that occupied the valley of the Inn as far down the Zillerthal, and the similar large glaciers that flowed om the Central Alps into the Etschthal and the Pusterthal nd the valley of the Drave. Lakes still occur immediately bove the terminal moraines of some of those large glaciers, s in the valley of the Drave.[1] But, as a rule, they have een filled up with detritus and alluvium. Such, for example, ould appear to be the case in the valley of the Inn above e opening of the Zillerthal.

The lakes in the high valleys of the Central Alps belong the 'second postglacial stage,' and have no representaves in the lower ranges of the Eastern Alps. During that age of minor glaciation these lower ranges appear to have pported no extensive fields of névé, and their higher valleys,

[1] The best example of a lake belonging to this stage, that I have seen, is at of Poschiavo, in the Bernina Alps. I have already referred to the Inn acier which headed in these mountains and flowed north-west down the ontresina valley. The Poschiavo glacier took its rise in the same region, but wed in exactly the opposite direction. As both glaciers came from the same at névé-field, it is interesting to compare them. The course of the Inn cier, it will be remembered, was not less than 125 miles, while that of schiavo, measured from the ice-shed to the large terminal moraines at the ver end of the Poschiavo lake, did not exceed twelve miles. The greater length ained by the former was of course due chiefly to the fact that it was fed on course by numerous tributary ice-flows--not a few of which were larger an the Poschiavo glacier itself.

therefore, contained no glaciers. Thus it will be seen that the distribution of high-level lakes harmonises with that of the terminal moraines. The lakes and local moraines of the lower ranges and mountain-groups belong to the 'first postglacial stage,' and are contemporaneous with the lakes and terminal moraines which occur in the main valleys that drain the Central Alps. On the other hand the high-level lakes and local moraines of the most elevated mountains are the relics of the final glaciation—that, namely, of the so-called 'second postglacial stage'—during which the lower ranges supported no glaciers.

Thus in the Alpine Lands we have evidence of five separate and distinct advances of the glaciers—the average elevation of the snow-line for each stage having been estimated by Professor Penck. During the first advance the snow-line, he thinks, must have been upon an average some 4,000 ft. lower than now. The second advance indicates a still greater depression—amounting probably to not less than 4,700 ft. The third glacial advance approximated in extent to the first, but was somewhat greater—implying an average depression of the snow-line below its present level of 4,400 ft. or thereabout. During the fourth advance, or that of the so-called 'first postglacial stage,' the snow-line would seem to have been 3,000 ft. lower than now, while the fifth and last general advance indicates a depression of about 1,600 ft. It must be understood that these are averages. The snow-line did not occur at the same level throughout the whole chain of the Alps during a glacial epoch any more than it does now.[1]

[1] Penck gives the height of the snow-line during the third glacial epoch for the following mountain-groups:—Bavarian Alps, about 1,300 metres; Lower Austrian Salzburg Alps, about 900 metres; Noric Alps, 1,500 to 1,700 metres; Fischbach Alps, 1,300 metres; Karawanken, 1,500 to 1,700 metres; Venetian Alps, about 1,300 metres. (*Vortrag gehalten in der Sect. Breslau des deutsch. u. oesterreich. Alpenvereins*, October 18, 1890.)

CHAPTER XXXV.

GLACIAL PHENOMENA OF OTHER PARTS OF EUROPE.

ɜlaciers of France—Glacial phenomena in Beaujolais and Lyonnais—oraines, &c., of the Morvan, of Mont Dore, &c.—Glacial and interglacial ɪenomena of Auvergne and Cantal—Moraines of La Madeleine, the Dor-ɔgne, and Aubrac—Glacial phenomena of the Pyrenees; evidence of ɜriodicity of glacial action—Glacial deposits of the Douro, the Serra da strella, the Sierra Guadarrama, the Sierra de Gredos, and the Sierra evada—Old glaciers of Corsica, of the Apuan Alps, and the Appenines—orrential deposits of Cosenza—Arctic and tropical shells of Italian post-iocene deposits—Glaciation in the Schar Dagh and the Rilo Dagh—lacial phenomena of Iceland and the Færöe Islands—Erratics in the zores—Breccias of Gibraltar—Rubble-drift and raised beaches of Northern rance.

ɪAVE dwelt so long upon the glacial succession of the Alpine Lands, that the corresponding phenomena met ı in the regions lying to the west and south must be ɪed in rapid review.

Mention has already been made of the remarkable fact ; the great glacier of the Rhone which occupied the ɪral depression of Switzerland attained so great a thick-ɪ that its upper strata overflowed through passes in the ɪ for long distances to the north and north-west. The ɪe range, however, had its own local glaciers, as was first ɪted out by MM. Lory and Pidancet.[1] Some of these ɪesced with the massive *mers de glace* that streamed out-ds from the Alpine Lands, as, for example, the glaciers he Valserine and the Semine in the southern part of the a,[2] but many others were independent, as we learn espe-ly from the researches of M. E. Benoît.[3] Similar facts, as have seen, have been recorded in connection with the ɪiation of the secondary chain of the Alps in Dauphiny

Comptes Rendus hebdom. des Séances de l'Acad. des Sciences, Paris, t. xxv. p. 718; *Bull. Soc. géol. de France,* 2e Sér. t. v. p. 20.
E. Benoît, *Bull. Soc. géol. de France,* 2e Sér. t. xx. p. 321.
Actes de la Soc. Helv. des Sciences nat. 1853, t. xvi. p. 231.

—a region which was likewise invaded by the vast *mers de glace* coming from the higher Alps. But before that invasion took place local glaciers had occupied the valleys of the lower ranges, and they again appeared after the vast *mer de glace* had vanished from their neighbourhood.[1]

Leaving now the immediate precincts of the Alpine Lands and crossing the valley of the Rhone, we encounter first the mountains of Beaujolais and Lyonnais, in the valleys of which Falsan and Chantre have discovered abundant traces of old glaciers. Of these the largest was that of the Azergues, the terminal moraines of which have been noted as far down as Lozanne, thus indicating an ice-flow of not less than twenty-five miles. The glacier of the Brevenne, which coalesced with it, was not much inferior in importance, while that of the Turdine (the terminal moraines of which appear as far down the valley as Bully) must have equalled and even surpassed many existing Alpine glaciers of the first order. The largest of the ice-flows just mentioned—that of the Azergues—descended from the slopes of the mountain-mass of Saint-Rigaud (3,320 ft.), from which as a central culminating point diverge certain other valleys, such as those of the Ardière and the Western Grosne, both pertaining to the basin of the Saône, and that of Sornin, a tributary of the Loire. Now in each of these valleys traces of ancient glaciers occur. During the height of the glacial period, therefore, Saint-Rigaud must have been enveloped in snow and névé, from which glaciers streamed out in all directions. Perennial snow-fields, however, existed at even lower levels in the same region, and gave birth to glaciers, amongst which may be mentioned the glacier of Mauvaise, whose gathering-ground did not exceed 2,600 ft. in height; the glacier of Vauxonne, and that of Nizerand, descending from nearly similar elevations. It is interesting to note that great sheets of gravel, &c., occur in connection with the terminal moraines of those ancient French glaciers—a vast *cône de déjection*, for example, spreading outwards from

[1] For an account of that most instructive region the reader should consult the great monograph of MM. Falsan and Chantre already cited, or the more general description given by the first-named author in his charming work *La Période glaciaire*.

e moraines of the Azergues glacier near Lozanne.[1] A little ther south rises the isolated mountain-group of Mont lat (4,900 ft.), which has likewise supported glaciers, the st important ice-flow having occupied the valley of the er.

More remarkable, however, is the occurrence of glacial enomena in the Morvan—a plateau-region in which the nne, a principal affluent of the Seine, takes its rise. The reme height of the Morvan is only 2,960 ft., but the servations of MM. Collenot[2] and J. Martins[3] show that s plateau was formerly snow-clad, and nourished consider-e ice-streams. Large erratics and morainic débris occur re or less plentifully round the Morvan—showing that the ciers streamed outwards in all directions from the domi-nt heights. The morainic accumulations, however, have dently suffered very extensive erosion. In many places ly the large blocks and a thin scattering of smaller erratics nain. There seems to be a general absence of well-eserved terminal moraines. Here and there, however, the orainic accumulations are better defined, and this occurs nen they occupy isolated heights—the excavation of the rrounding depressions by running water having, according M. Collenot, tended to their preservation. Vast sheets of ivio-glacial gravels spread outwards down all the valleys nd extend even into the Paris Basin, where erratics derived om the Morvan have long been recognised.

Auvergne, so famous for its volcanic cones and lava-flows, not less interesting on account of its glacial phenomena. he erratic accumulations of that region early attracted the tention of French geologists (1827), by whom, according the prevalent notions of their day, they were attributed débâcles. M. Lecoq, at a later date (1862), recognised in e valleys that descend from Mont Dore many of the pearances which are characteristic of the valleys of the ps, and the 'diluvial deposits' themselves he termed errain névéen.' He thus, as M. Falsan remarks, came

[1] Falsan and Chantre, *op. cit.* t. ii. p. 399; Falsan, *Esquisse géologique du rain erratique, &c., du bassin du Rhône* (Lyons), p. 107; *La Période gla-ire*, p. 319.
[2] *Bull. Soc. géol. de France*, 2ᵉ Sér. t. xxvi. p. 173; *ibid.* 3ᵉ Sér. t. vii. 520.
[3] *Ibid.* 2ᵉ Sér. t. xxvii. p. 225.

very near to the truth but failed to grasp it. It is to M. Julien [1] that belongs the honour of having been the first to show that the 'terrain névéen' of M. Lecoq was a true glacial accumulation. It will be remembered that Auvergne is for the most part a high plateau-region—the plateau built up of old crystalline rocks and supporting numerous volcanic cones, of which the most important are Puy de Dôme (4,806 ft.), Mont Dore (6,188 ft.), and Cantal (6,093 ft.). From each of these centres glaciers are now known to have flowed; but my space will not allow of a particular reference to more than one or two, which, on several accounts, are especially worthy of notice. Among the most interesting of the glacial accumulations of Auvergne are those met with in the valley of the Couze d'Issoire. Here M. Julien discovered evidence of two epochs of glaciation, separated the one from the other by a long interval of time. The moraines of the first epoch occur upon the plateaux and heights; those of the second epoch are met with in valleys which were excavated during interglacial times. M. Julien's conclusions are amply sustained by the independent researches of M. Rames, who for many years past has devoted himself to the study of Cantal.[2] This geologist also recognises two distinct series of glacial deposits—the older accumulations being exclusively confined to the plateaux and heights—the younger deposits occurring in valleys excavated since the disappearance of the earlier ice-flows. Great erratics are sprinkled over all the slopes of the enormous volcanic cone of Cantal, and here and there they appear in such prodigious numbers that the country-folk have styled them 'cimetière des enragés.' But erratics and glacial detritus are not confined to the slopes of the cone. They extend outwards for long distances over the surface of the plateaux, and with them are associated sheets of fluvio-glacial gravels, which now and again attain a very considerable thickness. The erratics, morainic débris, and associated gravels form what M. Rames terms the 'ancient diluvium of the plateaux.' At the time of their formation the great volcanic massif of

[1] *Des Phénomènes glaciaires dans le Plateau Central de la France*, &c., 1869.

[2] *Géogénie du Cantal*, 1870; 'Réunion extraordinaire à Aurillac (1884) de la Soc. géol' (*Bull. Soc. géol. de France*, 3e Sér. t. xii. p. 782).

antal did not show the highly denuded aspect which it now resents. It formed an immense depressed cone with a omewhat irregular surface, but the profound ravines and alleys that now trench its flanks had not as yet come into xistence. According to M. Rames, the cone was also coniderably higher than at present, and may have attained an levation of more than 9,500 ft. Such were the conditions at obtained at the beginning of the Ice Age. Glaciers then rmed in all the depressions upon the slopes of the extinct olcano, and flowed outwards in every direction upon the lateaux. The trend of these ancient glaciers appears to ave been quite independent of the existing valleys—the xcavation of which took place at a later date. The work f erosion probably commenced with the final melting of the e-streams and their névé-fields, and was carried on during prolonged interglacial epoch. Thus, before the next cold poch supervened, ravines and valleys had been dug out to lepths of 900 ft. and more. To such an extent, indeed, as the denudation been carried that in many places the ncient morainic débris of the first glacial epoch now appears apping the summits of more or less isolated hills. But the xtent of the erosion is not so remarkable as the fact that nost of it was accomplished before the next, or younger, eries of moraines was deposited. We are thus compelled o admit that a long period separated the older from the ounger glacial epoch of Auvergne. The phenomena refuse o be explained on the supposition of a short temporary etreat and re-advance of one and the same series of glaciers. The older morainic accumulations are scattered over the lateaux and heights, the younger moraines occupy valleys hat were excavated during interglacial times. And the state f preservation of the two series of deposits is in keeping with heir relative antiquity. While the older moraines have all he marks of great age—being highly denuded—the younger ccumulations are comparatively fresh—the terminal moaines forming conspicuous ridges and cones. Such, for xample, are those of the valley of Allagnon (Cantal). The lacier which deposited those moraines took its rise in a vast irque, some five miles in diameter, surrounded by heights arying from 5,900 to 6,100 ft., and flowed for a distance of

twelve and a half miles. Equally conspicuous and well-preserved are the moraines of the glacier of the Cère. In this valley two series of frontal moraines are met with, the lower series occurring some seven miles in advance of those farther up the valley. The latter form a well-marked ridge across the valley, and are cut across by the river and well exposed in the railway-cutting near Carnéjac. The surface of the moraine is sprinkled with enormous erratics, and in the deep railway-cutting the structure of the interior is clearly exposed. As in all the moraines of Cantal, rounded stones and sand are very abundant, but here and there angular fragments and great erratics appear, and now and again striated stones may be detected. This moraine, like the one which occurs farther down the valley, marks a long-continued pause of the glacier—and a similar double series of moraines may be seen in all the principal valleys of Cantal. Between the two series many little moraines of retreat occur in the bottoms of the valleys.

It is a natural inference that all these valley-moraines have been deposited by one and the same series of glaciers. We may suppose that after reaching its farthest limits each glacier maintained its position for a considerable time. Then it commenced to retreat somewhat rapidly for a distance of seven miles, less or more as the case may have been. Next came another long pause, during which the upper large frontal moraines were accumulated; and thereafter the final retreat was accomplished more or less continuously. But it may be remarked that the phenomena are equally explicable on the supposition that the two series of valley-moraines mark two separate and distinct advances of the glacier.

I must now draw attention to the observations of M. Marcellin Boule[1] on the interglacial deposits of Aurillac (Cantal). The plain of Arpajon opposite the mouths of the beautiful valleys of the Cère and the Jordanne, which descend from the massif of Cantal, is formed of two broad terraces, whose surface is fifty feet above the alluvia of the existing streams. These terraces have been formed largely at the expense of pre-existing moraines, for amongst the mass of

[1] 'Essai de Paléontologie stratigraphique de l'Homme,' *Revue d'Anthropologie*, 1889; *Bull. de la Soc. philomathique de Paris*, 8e Sér. t. i. p. 87.

and sand occur now and again angular erratics of large sions. In these gravels M. Rames obtained a number t implements, which were accompanied by large bones, and waterworn, obviously those of an elephant. The e age of the terraces is readily fixed. They are later he morainic débris of the plateaux, and when followed valleys they are seen to pass under the moraines of econd ' glacial epoch. They are thus clearly of inter- age. M. Boule remarks that flint implements of the form as those that occur in the gravel-terraces (the so- type of Saint-Acheul) are met with also frequently at ırface, 'but only in regions that lie outside of the of activity of the later glaciers.' Thus they occur ly on the low grounds beyond the frontal moraines, but pon the territories occupied by the old morainic accu- ons of the plateaux and heights. Flint implements of types, however (so-called Mousterian, Magdalenian, olutrian types), are found upon the surface of plateau- ıes and valley-moraines alike. Prehistoric man lived ntal, therefore, during interglacial times, and he ed the valleys also after the later glaciers had dis- ed. It is interesting to note that flint imple- have been met with in that region up to a height of t.

aces of glacial action have been detected in other s of Central France. Thus, according to M. Tardy, are encountered amongst the mountains of La eine.[1] M. Marcou has also cited the occurrence of rratics, morainic débris, and scratched stones at seve- ces in the valley of the Dordogne, west of the moun- of Auvergne.[2] Again, in the mountains of Velay ft.), Julien,[3] Tardy,[4] Torcapel,[5] and Aymard[6] have d what they took to be morainic accumulations. ing to M. Boule,[7] however, the deposits referred to

ll. Soc. géol. de France, 3e Sér. t. i. p. 514.
d. 2e Sér. t. xxvii. p. 361. 4 *Annuaire du Club Alpin*, 1886.
ll. Soc. géol. de France, 2e Sér. t. xxvi. p. 1178.
l. 3e Sér. t. vi. p. 606.
Préhistorique dans la Haute-Loire, 1888.
scription géologique du Velay,' *Bull. d. Serv. de la Carte géol. France*,
'o this work I am indebted for the references to the works by Julien
ard cited above.

by them are not of glacial origin. Some of them he thinks are simply the products of rock-falls and landslips, others are the relics of disintegrated lava-flows, while in many cases the accumulations are of torrential origin. The topographic features of the mountains of Velay are not such as would favour the formation of glaciers. They form a series of isolated peaks upon the plateaux, and the ravines which furrow their flanks are of little depth.[1] M. Boule thinks it probable, however, that glaciers may have existed in some of the valleys that drain towards the Rhone. These valleys end in cirques and may well have been occupied by glaciers, but they have not yet been critically investigated. Although no true glacial moraines can be cited from Velay, M. Boule is of opinion that much of the detritus, more or less abundantly developed in that province, is of Pleistocene age. No permanent glaciers seem to have existed, but there is nevertheless evidence of the effects that would result from the melting of thick snow—erosion on a large scale, and the transport of great sheets and masses of coarse rock-débris.[2]

South of Cantal rises the basaltic plateau of Aubrac (4,800 ft.), in the valleys of which true moraines occur,[3] and similar conspicuous evidence of glacial action has been recorded by Ch. Martins from the Cevennes.[4] From the width and height of these last-named mountains (4,500 to 5,500 ft.) one might have expected them to have furnished more abundant traces of glaciation than those which Martins studied in the valley of Palhères. But, as M. Falsan has remarked, this is due in all probability to the fact that the region has not yet been sufficiently investigated.

The chain of the Pyrenees, some 370 miles in length, presents certain features that distinguish it from the Alps. The latter, it will be remembered, consists sometimes of a series of roughly parallel ranges separated by broad longi-

[1] M. Boule remarks, however, that he has found striated stones in the Pliocene alluvia of Pépinière (valley of the Loire), but it is difficult to prove, he says, that the striæ are the work of ice (*op. cit.* p. 213).

[2] It seems not at all unlikely that much of this detritic material may have had an origin similar to that of the breccias of Gibraltar (see *postea*) and the 'rubble-drift' of Southern England.

[3] G. Fabre, *Comptes Rendus de l'Acad. des Sci.* t. lxxvii. (1873) p. 495.

[4] *Mémoires de l'Acad. des Sci. et Lettres de Montpellier* (Sect. Sci.), t. [illegible] p. 135; *Comptes Rendus de l'Acad. des Sci. (Paris)* t. lxvii. p. 933; *Quart. Journ. Geol. Soc.* vol. xxv. p. 46.

linal valleys; sometimes of more or less closely associated
›ups of mountains—the Pyrenees, however, show only
e great crest, and therefore have no longitudinal valleys
:responding to those of the Upper Rhone, the Inn, &c.
l the valleys, in short, are transverse to the direction of the
ain—those descending to the north communicating across
› dominant ridge by single cols or passes with a similar
ies of valleys opening southwards. The principal peaks
the Pyrenees range in height from 8,500 ft. to 11,170 ft.,
l as the snow-line attains a mean elevation of 9,000 ft.,
is obvious that the snow-fields must be of limited
ent. It is only in the loftier parts of the range, indeed,
it névé and glaciers are met with, and these last form
re patches, as it were, on the slopes of the highest moun-
ns—the largest glacier (that of the Vignemale) ending,
er a course of about two miles, at a height of 7,200 ft.
›ve the sea.[1] Viewed from the south the crest of the
in appears bald and naked, and even the northern slopes
the mountains throughout long stretches show, in the
ght of summer, no snowy covering. Only here and there
the highest ridges and peaks flecked with snow and
›tted with small glacier-patches. During the glacial
iod, however, these mountains presented a very different
pearance—great glaciers flowing north and south from the
minant crest. Dr. Penck has shown that the snow-line
that time stood some 3,600 ft. lower than at present, and
it, just as is the case in our own day, it gradually rose
m west to east. Thus in the Western Pyrenees the
esent snow-line is reached at a height of about 2,600 metres
530 ft.); in the central part of the chain at 2,800 metres
187 ft.), and in the Eastern Pyrenees at 2,900 metres
515 ft.). Now, according to Penck, the snow-line of the
acial Period attained a height of 1,700 metres (5,578 ft.)
the Central Pyrenees, while in the Eastern Pyrenees it
rtainly exceeded 1,750 metres. The same observer has
awn attention to the fact that the glaciers which descended
e northern slopes of the chain were considerably larger
an those that flowed southwards—a contrast which is

[1] A. Penck, *Zeitschr. d. deutsch. u. oesterreich. Alpen-Vereins*, 1884, 459.

likewise in keeping with present conditions—for with few exceptions névé-fields and glaciers are now restricted to the French side of the mountains.

West from the valley of the Saizon no trace of glaciers has been met with either in Spanish or French territory. No *roches moutonnées*, no moraines, no erratics, and no fluvio-glacial terraces are seen, and there is likewise an entire absence of cirques and cirque-lakes in that region.[1] East of the Saizon, however, all the great valleys descending to the north have been occupied by trunk glaciers formed by the union of many tributary ice-streams. Those that drained the most extensive areas deployed upon the low grounds at the foot of the mountains, while others with a more limited catchment-basin did not succeed in escaping from the mountain valleys. The largest of all was the glacier of the Garonne, which flowed from a height of 8,400 ft. and dropped its terminal moraines in the neighbourhood of Montréjean, 1,500 ft. above the level of the sea. It had thus a total length of forty-five miles or thereabout. At the epoch of its greatest extension it attained in its lower reaches a thickness of over 2,600 ft., forming a broad and deep *mer de glace* that overflowed through passes into adjoining valleys. In short, only the principal peaks and their buttresses showed above the surface of this great ice-flow. Another large glacier was that of the Ariège, which had a course of thirty-eight miles—its frontal moraines occurring at Foix. Its chief affluent—the glacier of Vic-Dessos—joined it at Tarascon, where the united ice-flow reached a thickness of more than 1,300 ft. The last of these French glaciers that I shall refer to is that of Argelès. This ice-stream, like those already mentioned, drained a wide region, and was consequently fed by many tributaries. Flowing from a height of 9,000 ft., it extended as far as Adé (1,300 ft.) after a course of thirty-four miles. At Luz the ice was at least 3,000 ft. thick, and from this point it diminished northwards to 2,600 ft. at Argelès, and 1,470 ft. at Lourdes. The most easterly valleys in which moraines, &c., have been detected are those of the

[1] Penck, 'Die Eiszeit in den Pyrenaeän,' *Mitt. d. Vereins für Erdkunde zu Leipzig*, 1883. (This paper gives references to the glacial literature); *Zeitschr. d. deutsch. u. oesterreich. Alpen-Vereins*, 1884, p. 459. See for later references Falsan's *La Période glaciaire*.

ìt and the Tech, which drain into the Mediterranean. ere glaciers descended from Mont Canigou and flowed : distances of over eleven and twenty-eight miles re- ectively.

The glaciers on the Spanish side of the Pyrenees were s extensively developed—thus affording the same contrast ιt obtained in the Alps between the snow-fields and .ciers of the opposite slopes of that great mountain-land. d doubtless the causes of that contrast were the same in ;h cases—the southern exposure and more rapid descent the mountains into the low-grounds of Italy and Spain pectively. The largest glacier of the Southern Pyrenees s that of the Gallego Valley—thirty-eight miles in length. cording to Penck, the Spanish glaciers had a mean length under twenty-five miles, and terminated at the level of 800 :tres (2,625 ft.) above the sea, while the average length of ; ice-streams on the French side exceeded thirty-eight les—their terminal fronts coming down to 500 metres 640 ft.) above the sea.

The general absence of large lakes at or near the mouths the mountain-valleys of the Pyrenees has often been narked upon. Lakes of the kind, however, are not entirely ιnting, and Penck has pointed out that just where the cient glaciers terminated, one may observe a basin or de- ession analogous to the silted-up lake-beds which appear the mouths of many Alpine valleys. In several cases, deed, the lakes in question have not been entirely oblite- ted, but are represented by little sheets of water—such, r example, as the lakes of Lourdes, Saint-Pédardet, and arbazan. It is obvious, moreover, that the relatively small aciers of the Pyrenees could not have excavated basins mparable in size and depth to those that were ground out ' the much greater ice-streams of the Alps. And if in the :ter region some of the old glacial lakes have been entirely ed up since glacial times, we need not wonder that a like ιe should have befallen the Pyrenean lake-basins. The es of several of these lakes are readily recognised. Thus ; extensive plain of Valentine, in the valley of the Garonne ɔve Saint-Gaudens, is obviously the bed of an old lake. So o in the valley of Lourdes a lake has formerly occu-

pied the bottom of that long depression; and the same has been the case in the valley of Ossau.

But although lakes are wanting in the lower reaches of the valleys, such is not the case in the heart of the mountains, where they are very numerous—numbering some 600, of which 170 are on the Spanish and 430 on the French side. They are all of small size, however, and occur chiefly in the bottoms of cirques—being for the most part 'corrie-lakes.' Some seem to be dammed by moraines—others occupy true rock-basins, such, for example, as the Laguna de Panticosa (147 ft. deep), and the Lac Bleu (120 acres in extent) on the western slope of the Pic du Midi de Bigorre, which is 380 ft. in depth. The larger number, however, are very much shallower. The cirques, whether containing lakes or not, do not occur under a height of 5,500 ft.

In the Pyrenees, as in Central France, evidence of the periodicity of glaciation is forthcoming. Many years ago (1867) Dr. F. Garrigou pointed out that in the valley of Tarascon (Ariège) the morainic deposits belonged to two separate glacial epochs.[1] Those of the earlier epoch occur abundantly at levels of 800 to 900 metres (2,625 to 2,953 ft.) above the sea, while the younger accumulations are met with on the bottom of the valley at 300 metres (984 ft.) above the same level. The two series are readily distinguished the one from the other. During the earlier epoch the glacier rose above the level of the Cave of Bouichéta, even to that of Pradières, which it filled with morainic débris. It is probable, according to Garrigou, that it was the water derived from the melting of the glacier which brought about the appearances seen in the Cave of Bouichéta—at that time, perhaps, occasionally occupied by man. In the deeper parts of the cave are found bedded sand and gravel, containing articles of human workmanship, all of which might have been carried inwards by fluvio-glacial waters—the objects having previously been left lying at the entrance.[2] According to the

[1] *Étude comparative des Alluvions Quaternaires anciennes et des Cavernes à Ossements des Pyrénées*, &c. (Toulouse, 1865); *Bull. Soc. géol. de France*, 2e Sér. t. xxiv. p. 577.

[2] According to M. Trutat, morainic débris has been introduced into certain Pyrenean caves by the glaciers themselves. He points to the occurrence of glacial striæ and scorings on the walls of the caves (*Les Pyrénées*, 1894, p. 86).

same observer the accumulations of the earlier glacial epoch are overlaid, betwen Rieux de Pelleport and Pamiers, by clays and marls of Miocene age. It is the same, he says, in the valley of the Garonne, where the older morainic deposits attain an enormous development, forming everywhere the base of the plateau of Lannemezan. Here, as in the valley of the Ariège, they are covered by the marls, clays, &c., of the Miocene; and precisely the same succession is met with in the valley of the Adour.[1] Dr. Garrigou's sections and descriptions leave no doubt that in all those valleys we have the deposits of two separate and distinct glacial epochs—of which the earlier was the more important. It is obvious, in short, that a long interval of erosion followed the accumulation of the older morainic accumulations, which were ploughed out by streams and rivers. It is in the newer valleys thus formed that the later moraines have been deposited. But additional evidence is required to prove that sedimentary formations of Miocene age overlie the older glacial accumulations. Garrigou's observations as to the occurrence of two glacial epochs of glaciation have been apparently confirmed by the researches of M. E. Trutat in the valley of the Tech (Eastern Pyrenees).[2] Near Bolou massive moraines overlie fossiliferous blue marls of Pliocene age, and these in turn are seen in open section resting upon an older morainic accumulation—both moraines being crowded with erratics and scratched stones. If this reading of the evidence be true, the earlier glaciation of the Pyrenees must date back to late Tertiary times. But if Garrigou is justified in assigning the old moraines described by him to the Miocene, then these clearly belong to an earlier stage than those of the Tech Valley.[3]

Again, M. Piette tells us that the frontal moraine of the glaciers of the Pique and the Garonne reposes upon the *moraine profonde* of an earlier glacier, the materials of which had

[1] *Bull. de la Soc. géol. de France*, 1873, p. 435.
[2] *Les Pyrénées*, 1894.
[3] Without having seen the sections I hesitate to call in question the conclusions of those who have described them. One may admit that there have been two epochs of glaciation in the Pyrenees—one separated from the other, as in Auvergne, by a long epoch of erosion; but the evidence as to the superposition of Miocene and early Pliocene beds upon glacial deposits must be re-examined before it is likely to gain acceptance.

previously been denuded and re-arranged by torrential water. At a depth of forty-six feet in this denuded and re-arranged bottom-moraine were found remains of a small ruminant, pieces of wood, and a fragment of a reindeer's horn. As to the glacial character of the *remaniée* moraine there could be no doubt, for some of the stones still retained their striæ, while the iceworn aspect of the contiguous mountain-slopes spoke to the former passage of a massive glacier. M. Piette further remarks that along the right banks of the Neste and the Garonne the hills are iceworn up to a height which was certainly not attained by the glaciers of the later glacial epoch. In short, it is clear that during some earlier glacial epoch the ice-flows of the Pique and the Garonne extended north considerably beyond the valley of Labroquère; that subsequently they retired, and their *moraines de fond* were denuded and re-arranged by torrential action; that afterwards they again advanced, but not to so great a distance, into the low-grounds.[1] It is obvious, indeed, that in the French low-grounds opposite the mouths of the mountain-valleys of the Pyrenees, we have, as Dr. Penck has pointed out, an 'outer' and an 'inner' zone of moraines comparable to the similar zones of the Alpine 'Vorland,' and probably indicative like these of successive epochs of glaciation. The same author has shown that the cirques and true corrie-lakes of the higher Pyrenees with their associated glacial phenomena are evidence of a distinct stage. The rock-basins in the bottoms of the cirques were excavated by small local glaciers long after the retreat of their massive predecessors from the lower valleys—local glaciers which indicate a snow-line 600 metres (1,968 ft.) lower than the present. They come under the category of the so-called 'postglacial glaciation' of the Alpine Lands.[2]

Terraces of fluvio-glacial gravels are well seen in the lower reaches of all the great valleys of the Pyrenees, and doubtless tell a similar tale to those of the Alpine regions, as described by Penck, Brückner, and others. In the valley of the Garonne they are specially well displayed, and occur at three

[1] *Bull. Soc. géol. de France*, 3e Sér. t. ii. pp. 503, 507.

[2] The evidence for an advance of glaciers in 'postglacial' times was, I think, first recognised by me. See *Prehistoric Europe*, p. 411 *et seq.*

rent levels. The width and height of these terraces at louse are given by M. Leymerie as follows:—

Highest terrace—width, 11,000 m.; height, 180 m.
Middle terrace—width, 5,000 m.; height, 152 m.
Lowest terrace—width, 4,000 m.; height, 140 m.

ccording to the late F. A. De Vasconcellos Pereira al, considerable glaciers have existed in the basin of the ro.[1] The mountains in which this river rises range in ht from 7,380 to 7,700 ft. The same author has given iteresting description of the glacial phenomena of the a da Estrella (5,500 to 6,500 ft.), the highest range of ntains in Portugal.[2] Notwithstanding the relatively low tion of these mountains, the valleys that descend from culminating ridges and plateaux exhibit all the charactic marks of glacial action—terminal moraines, bottomines, *roches moutonnées*, striated rocks, cirques, and lakes. largest of the glaciers was that of the valley of the re—the terminal moraines of which occur at a distance xteen miles from the source of the present river. The om-moraine forms a stony clay (*argilla pedregosa*) comble to that of regions already described. It is notehy that near the very head of the valley a very freshing terminal moraine, 160 ft. or so in height, forms a picuous feature.

)f the glacial phenomena of the Sierras of Spain little is to be known. Don Casiano de Prado has described 'diluvial' deposits of the Sierra Guadarrama (7,000 to 0 ft.),[3] and M. Baysselance has noted the occurrence of *es moutonnées*, glacial striæ, and moraines in the same on, between Torre Lodones (2,625 ft.) and Avila (3,700 In the valley of the Jerte, which descends from the tern extremity of the Sierra de Gredos (7,900 ft.), the e observer records the appearance of terminal and lateral aines at a height of 1,770 ft. above the sea.[4] Lastly,

Estudos de depositos superficiaes da bacia do Douro. Lisbon, 1881.
Revista de Obras Publicas e Minas, t. xv. No. 177, 178, 1884; *Communi-s da Commissaõ dos Trabalhos geologicos de Portugal*, tom. i. (1887) 9.
Descripcion fisica é geologica de la Provincia de Madrid, p. 164.
Journal d'Histoire naturelle de Bordeaux et du Sud-Ouest, 3e année, p. 38; *du Club Alpin Français*, t. x. (1883) p. 410.

reference may be made to the glacial phenomena of the Sierra Nevada, long ago referred to by MM. Schimper and Collomb.[1]

Some forty years have now elapsed since Collomb discovered in Corsica the moraines of a glacier which had descended from Monte Rotonda (8,612 ft.). The moraines occur at a height of 1,410 ft.[2] The valleys coming down from Baglia Orba (8,694 ft.)[3] and Monte Cinto (8,892 feet)[4] in the same island also exhibit similar traces of ancient glaciers. More remarkable, however, is the occurrence of moraines, &c., in the Apuan Alps (Tuscany), which do not exceed 6,700 ft. in elevation. Professor Cocchi appears to have been the first to detect traces of glaciation in this littoral range of mountains,[5] and subsequently similar evidence was obtained by Professor Stoppani.[6] Towards the head of the Val d'Arni, descending from Monte Altissimo (5,216 ft.), a well-marked moraine crosses the valley. The morainic matter consists of a chaotic mass of blocks and débris of white marble, together with various schists, some of the stones being striated. Like many moraines largely composed of calcareous rocks, this one has become indurated in places by the percolation of superficial water. Professor Moro has described what he takes to be morainic accumulations, abundantly developed in the valley of the Serchio.[7] These, he believes, betoken the former presence of a great glacier which covered a considerable portion of Tuscany. The accumulations in question are highly tumultuous and certainly very closely resemble glacial débris—alike in form, structure, and distribution. According to Moro the glacier abutted on Monte Pisano (3,000 ft.), and there bifurcated, the smaller branch passing to the west down the valley of the Serchio, the right and larger branch dilating upon the wide irregular plain that extends east to the foot of Monte Albano. The

[1] *Bibl. Univ. de Genève* (*Arch. d. Sciences phys. et nat.*), t. xxi. (1852), p. 295.
[2] *Bull. Soc. géol. de France*, 2e Sér. t. xi. p. 66.
[3] Pumpelly, *Bull. Soc. géol. de France*, 2e Sér. t. xvii. p. 78.
[4] De Grandsaignes, *Bull. Soc. géol. de France*, t. xxvi. p. 270.
[5] *Atti Soc. Ital. Sci. nat.* t. ii. (1886); *Boll. R. Com. Geol. d'Italia* (1872), t. iii. p. 187.
[6] *Rendiconti del R. Istituto Lombardo*, t. v. p. 733; *Atti Soc. Ital. Sci. nat.* t. xv. p. 133; *Geologia d'Italia*, pte. 2e, p. 127.
[7] *Il gran Ghiacciajo della Toscana*, 1872; see also Stefani, *Boll. R. Com Geol. d'Italia*, 1874, p. 86; *ibid.* 1875, p. 1.

al moraines of this branch extend along the right bank ıe Arno between Fucecchio (Monte Albano) and the rn foot-slopes of the Monti Pisani. The lake of tina, which occurs within this morainic zone, is com- ɔle, according to Moro, to the inter-morainic lakes h occupy similar positions at the base of the Alps in h Italy, such as Avigliana, in the 'morainic amphi- re' of the Dora Riparia, and those of Viverone and ɜo in that of the Dora Baltea. No scratched stones, ver, appear to have been detected in any of these ɔsed morainic accumulations of the Val Serchio glacier, we must remain in doubt, therefore, as to whether ı's interpretation of the evidence is thoroughly well- led.

eeing that terminal moraines occur in the Apuan Alps ɔwing that glaciers have flowed from heights of little than 5,000 ft., we might expect to meet with similar nce in some of the high valleys of the Appenines. To ɔest of my knowledge, however, the only traces of old ɜrs hitherto recognised are those described by Stefani as ating an ice-flow from the heights of Corfino north of ɜlnuovo di Garfagnana into the valley of the Serchio, and noraines, erratics, and glacial lakes of Monte Majella 7 ft.) in the Abruzzi as described by Signor Ferrero.[1]

[ention has been made in a previous page of the ntial accumulations of the Ligurian coast-lands. In hern Italy somewhat similar deposits have been met In the province of Cosenza they form well-marked ces which extend from the foot-slopes of the Appenines e west coast, where they terminate in a more or less ɒt scarp overlooking the recent raised beach of that n. The terraces in question vary in height from 30 to t. above the sea at their lower extremity, and rise with ntle gradient inland to all heights between 165 and ft., and sometimes even to 500 ft., until they terminate ıst the rocky spurs of the Appenines. Deep ravines been cut through them by the streams and torrents ɜnding from the mountains. They are composed of ɜe shingle and gravel, amongst which are many angular

[1] *L'antico Ghiacciajo della Majella*, 1862.

and subangular stones, commingled more or less abundantly with sand and clay. The bedding is horizontal, or gently inclined towards the sea, and has a characteristic torrential aspect—there being no trace of marine sedimentation. Signor Francesco Salmojraghi, who has described these terraces in some detail,[1] is of opinion that they are *cônes de déjection* thrown down by the torrents of the Glacial Period. The cones appear to have encroached upon the sea, the waves being impotent to oppose their advance. Towards the close of the Glacial Period, however, when the torrents declined in importance, the heaps were gradually undermined and truncated by the sea, while at the same time the streams commenced to hollow out the ravines by which the terraces are now intersected.

Here brief reference may be made to the occurrence in the post-pliocene marine beds of Italy of a large number of molluscan species which are not met with in the Pliocene beds of that country, and do not now exist in the Mediterranean.[2] Amongst these are many North Atlantic forms, such as *Waldheimia cranium*, *Cyprina islandica*, *Mactra solida*, *Panopæa norvegica*, &c., and others which are exclusively boreal and arctic, as *Tellina calcarea*, *Mya truncata*, var. *uddevallensis*, *Pecten islandicus*, *Trachysma delicatum*, *Buccinum undatum*, &c. There can be little doubt that this fauna was contemporaneous with the glacial conditions of Central and Northern Europe. It is very noteworthy that the strata immediately succeeding the boreal and arctic shell-beds of Sicily yield a number of southern species which are wanting in the Pliocene, and have disappeared from the Mediterranean. Amongst these are *Tornatina Knockeri*, now living on the west coast of Africa; *Conus testudinarius*, off Cape Verde Islands; *Terebra corrugata*, var. *regina*, on the Guinea coast; *Triton ficoides*, and *Strombus bubonius*, on the coast of Senegal; *Natica orientalis*, in the Indian Ocean; *N. porcellana* and *Loripes Smithii*, off the Canaries; *Diplodonta Savignyi*, in the Red Sea. Some tropical forms, such as *Cassis sulcosa*, are still met with in the Mediterranean. To account for

[1] *Boll. R. Com. geol. d' Italia*, vol. xvii. (1886) p. 281.

[2] Stefani, 'Les Terrains Tertiaires Supérieurs du Bassin de la Méditerranée,' *Ann. de la Soc. géol. de Belg.* t. xviii. p. 394.

ıe appearance of these tropical forms, Seguenza has peculated upon a former wide communication having obained between the Mediterranean and the Atlantic across frica.[1] Of this, however, we have no direct evidence, and ıe phenomena, as it seems to me, are explicable in a simpler 'ay. As we must suppose that the boreal and arctic forms nmigrated into the Mediterranean when the current enterıg by the Straits of Gibraltar was much colder than now, so 'e may infer that the tropical types were introduced at a ,ter date by the same route when the current was warmer ıan at present. This is a point, however, to which reference ill be made when I come to discuss the general question of leistocene climatic conditions.

Very little is known of the glacial phenomena of the ountain-regions of South-eastern Europe. Cirque-lakes ıve been observed in the Schar Dagh (10,000 ft.) of lbania[2] and the Rilo Dagh (9,600 ft.) of Bulgaria,[3] but therto they have not been seen elsewhere in the Balkan ninsula. In the Caucasus, moraines, erratic blocks, *roches outonnées*, and other evidences of former extensive glaciaon have been recorded, more especially by M. Abich.[4]

We may now take a rapid glance at the European islands the Atlantic. Iceland, as might have been expected, fords abundant proofs of former intense glaciation. W. ırtorius von Waltershausen appears to have been the first 846) to detect glacial striæ in that country,[5] and they have en frequently noted by various travellers since the time of s visit, as by Kjerulf,[6] R. Chambers,[7] O. Torell,[8] Paijkull,[9] elland,[10] Keilhack,[11] and myself.[12] Recently we have from r. Th. Thoroddsen a very interesting detailed description

[1] *Atti R. Accad. dei Lincei*, Ser. 3., *Mem. d. Classe di Scienze fis. mat. e t.* vol. vi. 1879.

[2] Rockstroh, *Mitt. d. k. k. geogr. Ges. Wien*, 1874, p. 482.

[3] Cvijić, *Bericht über das XVI. Vereinsjahr d. Ver. d. Geogr. Wien*, 1891, 46.

[4] *Bull. de l'Acad. impér. d. Sciences de St.-Pétersbourg*, t. xvi. p. 245.

[5] *Natuurk. Verh. Holl. Maatsch. Wettensch.* Dl. xxiii. pp. 76, 79.

[6] *Nyt Mag. for Naturvidensk.* t. vii. p. 56.

[7] *Tracings in Iceland and the Færöe Islands*, 1856, p. 49.

[8] *Öfvers. af k. Vetensk.-Akad. Förhandl.* 1857, p. 326.

[9] *Bidrag till Kännedom om Islands bergsbyggnad*, p. 12.

[10] *Geografisk Tidskrift*, 1882, t. vi. p. 104.

[11] *Zeitschr. d. deutsch. geol. Ges.* Bd. xxxviii. (1886) p. 435.

[12] *Nature*, vol. xxiv. (1881) p. 605.

of the past and present ice-fields of the island, from which we learn that the whole land was formerly smothered in ice, which moved out in all directions to the coast.[1] According to Thoroddsen the Icelandic *mer de glace* attained an average thickness of about 1,000 metres in the interior of the island, and diminished to about 400 to 500 metres on the coast-lands. His observations lead him to believe that the surface-slope of the ice, like that of Greenland, was very gentle, and he thinks that the great dome of the Vatna Jökull (6,000 ft.) must have been buried in ice to such a depth, that its upper surface was at least 800 metres (2,625 ft.) higher than now.

Towards the close of the Glacial Period, when the ice-fields were becoming reduced in importance, submergence ensued, and the lowlands in the south and west of Iceland were overflowed by the sea. In the north-west of the island rock-terraces (Strandlinier) occur at a height of 70 to 80 metres above sea-level, and these, according to Thoroddsen, mark the limits of the submergence. At this time glaciers still occupied the smaller fiords, the presence of which prevented the formation in such places of 'Strandlinier,' while large ice-flows deployed upon the wider bays, over the beds of which their silt and clay were distributed. These deposits are charged with the shells of *Yoldia arctica* and other high northern forms. As the climate became less severe, and the ice-fields continued to diminish in extent, the sea began to retire—its retreat being marked by the formation of a series of beaches, of which the most distinct is one that occurs at a height of thirty to forty metres above the present coast-line. The arctic marine fauna had meanwhile disappeared, and the sea was tenanted by the same forms as are at present met with on the Icelandic coasts—which were then haunted by large numbers of walrus. As many of the beaches and rock-terraces at this level are met with in the small fiords of the north-west coast, we gather that glaciers had now for the most part disappeared from those fiords. Since then the sea has gradually retired, the line of its retreat being marked by accumulations of shells and drift-wood. There are good grounds for believing, Thoroddsen remarks, that this retreat

[1] 'Islands Jökler i Fortid og Nutid,' *Geografisk Tidskrift* (1891–2); *Bihang till K. Svenska Vet.-Akad. Handlingar*, Bd. xvii. Afd. ii. No. 2, p. 74.

f the sea (on the north-west coast at least) is still in proress, although no direct measurements of the movement ave been made.[1]

The Færöe Islands have likewise supported an indepenent ice-sheet of their own. In 1879 I visited these islands 1 company with my friend, Dr. Amund Helland, and we raced the spoor of the ice throughout the group. We found hat the upper surface of the ice rose in the northern islands o a height of 1,600 ft., and in Süderoe of 1,400 ft. above what is now the sea-level. Not only so, but the ice was so nick that it filled up all the fiords and the sounds between ne various islands, so as to form one compact *mer de glace* nat flowed outwards in all directions from the dominant eights to discharge its icebergs into the surrounding ocean.[2] t is noteworthy that no 'raised beaches,' like those of celand, occur in the Færöe Islands.

Upwards of thirty years ago Herr Hartung described ne occurrence of erratics, many of them more than a foot 1 diameter, in the Azores. They consist of coarse gneiss, ompact limestone, quartz, graphic granite, and various other arieties of granite. They are met with at low levels on and ear the coast, in the islands of Terceira and Santa Maria. Ierr Hartung did not believe the blocks could have been rought to the islands as ballast, nor is it possible that those which occur at some little distance inland could have been arried by man's hand or swept thither by the waves of the ea. He is of opinion that they have been brought by floating ce that stranded on the islands when these were slightly lepressed below their present level. Santa Maria is in 37°, nd Terceira in 38° 45′ N.L.[3]

Returning now to the continent of Europe, I have to lraw attention to another set of phenomena which are trongly suggestive, not of glaciation properly so called, but ievertheless of severe climatic conditions. I refer to the reat accumulations of earthy débris and rock-fragments, so

[1] 'Postglaciale marine Aflejringer, Kystterrasser og Strandlinjer i Island,' *Geografisk Tidskrift*, 1891–92; *Bihang till K. Sv. Vet.-Akad. Handl.* Bd. xvii. Afd. ii. No. 2, p. 80. See also K. Keilhack, *Zeitschr. d. deutsch. geol. Ges.*, 1884, . 145.

[2] Helland, 'Om Færöernes Geologi,' *Geografisk Tidskrift*, 1881; J. Geikie, *Trans. Royal Soc. Edin.* vol. xxx. p. 217.

[3] *Die Azoren*, &c. (1860) p. 294.

abundantly developed in many parts of Europe, which we have no reason to believe ever supported true glaciers. The rubbish-heaps in question are very similar to the more or less unconsolidated sheets of rock-débris which form in arctic regions and on mountain-slopes in our own and other temperate and south-temperate regions. The peculiarity of the 'rubbish-heaps' I am about to describe is this, that they occur in places where they are no longer accreting, but becoming disintegrated and denuded. Obviously the conditions favourable to their formation have passed away. An excellent example is furnished by the massive breccias of Gibraltar, which have been described by Sir A. C. Ramsay and myself.[1] These consist of rude accumulations of angular fragments of limestone, of all shapes and sizes, embedded in a calcareous grit and earth. The masses vary in thickness from a few feet up to thirty or forty yards. They are met with here and there, clinging to the upper slopes of the Rock, but occur in greatest abundance upon the low ground, and thicken out as they approach the sea. All the materials have been derived from the Rock itself, and the accumulations are obviously of subaërial origin, and of great antiquity. This is shown by their highly-furrowed and worn aspect, and by the fact that since the time of their formation terraces have been eroded in them by the sea during some period of submergence. The sharply-angular character of the fragments in these breccias, and the large size attained by many of the blocks, some of which must weigh twenty or thirty tons at least, attest the former action of frost.

There was a time, then, in the geological history of Gibraltar when the winters were so severe that the limestone-beds (of which the Rock is chiefly composed) were ruptured and shattered, and the slopes became covered over with sheets of loose angular débris and large blocks. But the fragments thus detached could not of themselves have travelled from the upper reaches of the Rock down to the coast. They might well have rolled down the more precipitous slopes, but they could not have continued their journey across the low-grounds, for a distance of 550 yards at least,

[1] *Quart. Journ. Geol. Soc.* 1878, p. 505. See also *Prehistoric Europe*, p. 216.

ıich the average inclination is not more than 8° d here and there does not exceed 2° or 3°. But if we ·pose that he Glacial hick snow the flanks Rock, we have all litions re- or the ori- ·ck-débris, ts transla- : the adja- ·-grounds. limestone break up ıe crest of ·e and on acclivi- l the loose ınd débris upon the of snow end to be ownwards movement ·vé. Vast es of rock- would gradually at the of the ınd when w melted ımer, the . becom- saturated, move for- ·n *masse*, : so-called

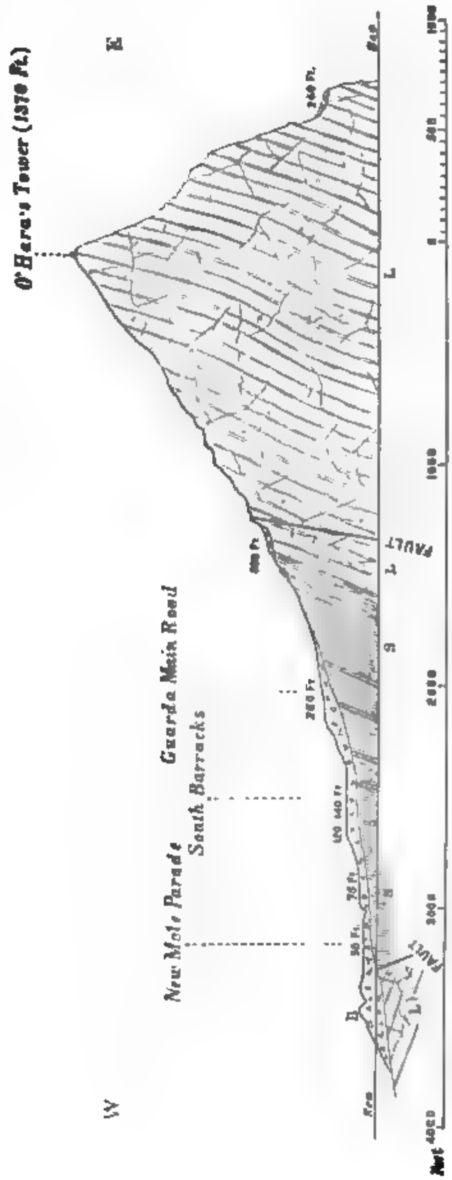


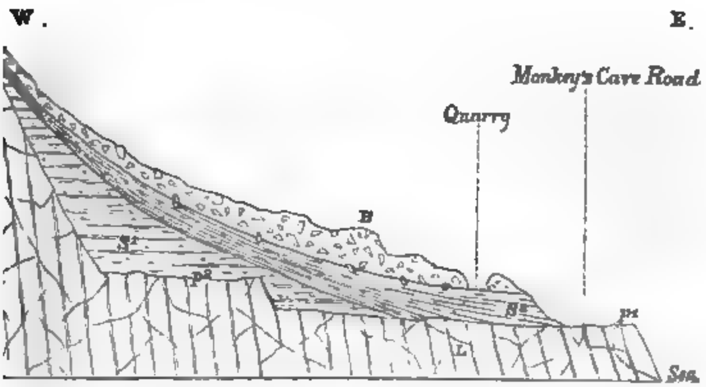
Fig. 77.—Section across Rock of Gibraltar. B, Limestone-breccia; L, Limestone; S, Shales. The figures denote height of raised beaches above sea-level.

earth-glaciers of the Rocky Mountains, as described by Hayden.

If the reader is startled by the suggestion that Gibraltar was probably snow-clad during the climax of the Glacial Period, he should remember that the Rock is 1,300 ft. in height, and that the mean temperature of the coldest month in the town (February) is 54° 2′, which implies a mean winter temperature of say 50° at the top of the Rock. Occasionally, but only at rare intervals, the temperature falls to the freezing-point in the town, and thin ice forms now and again at the signal-station (1,294 ft.). When it is borne in mind that in glacial times perennial snow and large glaciers existed in the Serra da Estrella, in the Sierra Nevada, in Corsica, in South Italy, and in the Turkish Provinces—in regions where they no longer appear—it does not seem hard to believe that the winter temperature of Gibraltar must have been considerably lower than now.

It is remarkable that the limestone-breccias of Gibraltar occur on two separate horizons. The accumulation of the one series of breccias was separated from the formation of the other by a prolonged period of time. I need not recapitulate the evidence, but will simply refer the reader to the description given by Ramsay and myself in the paper already cited, and to 'Prehistoric Europe,' in which our data and conclusions are summarised. From the latter work I may be allowed to cite the following remarks:—'The accumulation of the breccia of the first cold epoch had ceased, and the loose agglomeration of grit and large and small blocks had become cemented into an indurated mass long before the formation of the later breccias was effected. Torrents had worn gullies in the older breccia, and acidulated water percolating through crannies and fissures had gradually opened out a series of subterranean galleries and caves, which penetrated the mass in the same manner as they traversed the subjacent limestone strata. All this took place at a time when Spain projected farther into the Mediterranean than it does now, and when the climate was mild and genial. At the period referred to, Gibraltar must have appeared as a verdure-clad alp towering above the surface of a wide expanse of undulating country that stretched south towards

coast of Barbary, with which, indeed, it may actually e been connected. The Rock was then tenanted by the ɛ in great numbers, and visited from time to time by ɔoceros, elephant, horse, boar, and deer, and by bears, ves, hyænas, lions, leopards, lynxes, and cervals, some which may have made their lair in one or other of its nerous caves. Now and again torrents flowing down slopes of the mountain swept the skeletons and carcasses these animals into gullies and underground galleries, ere they gradually accumulated along with other super-al débris, and became in time sealed up by the action of bonated waters. Eventually, however, a process of sub-



. 78.—Showing relation of Upper or Younger Breccia to Raised Beaches —Gibraltar L, Limestone; S¹, Beach-deposits; S², Rearranged beach-deposits; B, Upper breccia; p^1 p^2, Marine terraces.

ergence ensued, and the land sank into the sea to the pth of 700 ft. or thereabout below its present level. This vement seems to have been interrupted by longer or orter pauses, during which the sea cut terraces or shelves on the flanks of the Rock—shelves which have been eroded tly in limestone and partly in the old limestone-breccia. e Figs. 77 and 78.) By-and-by the submergence ceased, l the land was again upheaved, probably in as gradual a nner as it went down. The old sea-shelves were then tially obscured by shelly sand and gravel which had hered over them; and from the fact that the shells, so as can be made out, belong to species identical with those

now living in the neighbouring sea, we gather that the temperature of the sea at least was at that distant date much the same as it is to-day. To what extent the land was re-elevated we cannot tell. It certainly attained a greater elevation than the present, but whether or not Spain stretched as far to the south as it did in the preceding period can only be conjectured. The sand that clothed the flanks of the Rock, acted upon by the weather, would sooner or later become "top-dressed," so to speak, and would thus form long sloping curtains or taluses, the surface of which would here and there tend to become indurated by the action of rain, dissolving the calcareous matter of the shells, and again redepositing it between the grains of the grit and sand. By-and-by, however, there ensued a second cold epoch, when the limestones commenced to break up under the action of frost, while their fragments were carried down as before to the low grounds. Large blocks and smaller fragments, toppling from the lofty cliffs that face the east, fell upon the sand-slopes, here and there plunging into them where the process of superficial induration had not been sufficiently advanced to enable the sand-rock to withstand the force of the impact. Thus in time the shelly sands came to be completely buried under a thick accumulation of angular blocks and débris, which, having since become thoroughly indurated, presents precisely the same character as the older limestone-breccias.'[1]

It would lead me into too much detail were I to attempt any general sketch of the heaps of rock-rubbish which occur in many other regions in positions where they are no longer accumulating. A particular account has been given of the so-called 'head' and 'rubble-drift' of the south of England, and some reference has also been made to the pseudo-morainic accumulations of Central France, which occur up to heights of 3,000 ft. and more. Similar heaps and sheets of rock-débris are encountered again and again in the mountainous parts of Southern Europe, as in the Sierras of Spain, in the Appenines, and in the mountains of the Balkan Penin-

[1] *Prehistoric Europe*, p. 325. In the same work will be found some account of the breccias of Malta, which seem to have been formed under severer conditions of climate than now obtain in the Mediterranean region.

Some of the rock-rubbish of those regions is doubt-
he result of great landslips and rock-falls, but in many
this cannot be so. Obviously the rocks have been
ın up by the action of frost, and have travelled outwards
the heights, over very gentle declivities, and for con-
ıble distances. Even in the low-grounds of Central
pe the loose Tertiary and Quaternary deposits often
foldings and contortions which recall the 'underplight'
'trail' so conspicuously developed in the Pleistocene
sits of Southern England. Dr. Fuchs has described the
rbed appearance of the unconsolidated formations met
in the Viennese basin,[1] which are bent and folded in a
remarkable manner. These foldings are clearly related to
xisting configuration of the ground, since they are not
confined to the slopes of the hills, but it is obvious that
naterials have moved outwards from the hills to the
ent flats.[2]

ı Northern France, as in Southern England, superficial
nulations of rock-rubbish and clay with flints are widely
oped. Concerning the origin of the clay with flints
ı has been written. In many cases it would appear to
mply the insoluble portion of chalk, which forms the
ıd-rock over a wide region in Northern France, and some
may well belong to an earlier age than the Glacial
ɔd. But not infrequently a clay with broken flints is
l spreading over all the rocks indifferently—chalk and
ıry deposits alike—and associated with Pleistocene gravels
ch a way as to indicate that it belongs approximately to
ame age as these. This is not a sedentary but a travelled

[1] *Jahrb. d. k. k. geolog. Reichsanstalt*, 1872, Bd. xxii. p. 309.

[2] Professor Prestwich, as already mentioned (see p. 389), believes the rubble-
of England to have been formed during a temporary submergence of
ft. or thereabout and subsequent more or less rapidly-effected emer-
of the land. More recently he attributes a similar origin to the 'rubble-
' of the Continent (*Proceed. Royal Society*, vol. liii. p. 80). I have
d those 'drifts' in many regions, and am quite unable to accept this ex-
tion. I think that they can all be accounted for by such action as I have
ted. It must not be forgotten, moreover, that the 'drifts' in question
in many places a much higher elevation than 1,000 ft. In Central
e they are seen at heights of 3,000 ft. and more; in the Pyrenees they
en higher; and they occur in the Black Forest and the Swabian and
onian Jura up to similar elevations. 'Pseudo-morainic' accumulations,
ɔrt, are commonly met with both at high and relatively low levels in many
of Central and Southern Europe.

deposit, for it has evidently moved down gentle declivities and spread itself out over lower levels. In other places we meet with more or less thick sheets of rock-rubble, comparable in every respect to the rubble-drift of Southern England, and occupying precisely similar positions. At Sangatte near Calais, for example, it caps an old raised beach which in many respects recalls that of Brighton (see p. 400). The series of deposits seen at Sangatte is as follows:—

3. Rubble-drift, composed chiefly of entire and broken chalk-flints and ferruginous sandstone, in a brown arenaceous clay, from 9 ft. to 23 ft. thick.

2. Comminuted chalk and sand in irregular alternating layers, and beds of loam, clay, sand, and chalky gravel, with fragments of flint, from 50 ft. to 80 ft. thick. Near the top of these beds remains of the mammoth have been obtained, and land-shells occur in numbers lower down, such as *Helix concinna*, *H. pulchella*, *Succinea oblonga*, *Pupa marginata*, &c.

1. Thin bed of coarse sand containing sea-shells (*Purpura lapillus*, *Littorina littorea*, *Tellina balthica*, *Mytilus edulis*, &c.) and resting upon a bed of coarse shingle, consisting chiefly of rolled chalk-flints, amongst which occur rolled fragments of other rocks (such as granite), foreign to the district. This shingle (6 ft. to 13 ft. thick) abuts against an old chalk-cliff.[1]

Mention also may be made of the raised beaches described by M. Barrois as occurring on the west coasts of Brittany.[2] He refers especially to beds of cemented gravel and shingle (ferruginous conglomerate) which are met with in various places up to a height of rather more than thirty feet above the sea. The conglomerates are unquestionably old beach-deposits, and consist partly of rolled stones and partly of angular fragments which have obviously fallen from the adjoining cliffs. Amongst the rolled stones, however, are many which have come from a distance. These could not have been brought by marine currents, neither could they have been swept down from the interior of the country by ordinary river-action. M. Barrois believes that they could only have been carried by floating ice. He pictures to himself, therefore, a time when ice-rafts descended the Loire and its tributaries, carrying with them erratics from the interior, and when ice also formed on the Atlantic coast, and aided in the distribution of erratics along the shores of Finisterre.

Farther east on the coasts of Normandy occur erratics

[1] Prestwich, *Quart. Journ. Geol. Soc.* vol. vii. p. 274; *Bull. Soc. géol. de France*, 3e Sér. t. viii. p. 547; Sauvage and Hamy, *Bull. Soc. géol. de France*, 2e Sér. t. xxiii. p. 643; Sauvage, *ibid.* 3e Sér. t. viii. p. 595; Ch. Barrois, *ibid.* p. 552.

[2] *Ann. de la Soc. géol. du Nord*, t. iv. p. 186; t. xii. p. 239.

various crystalline rocks (granites, granulites, amphibolites, .) measuring over one cubic metre in size. M. Vélain regnises these as having come from Brittany, and is of inion that during glacial times local glaciers existed in tentin and descended the fiord-like valleys to the sea, iere they calved their icebergs, which by tidal currents and e prevalent west wind were borne eastwards to the coast Normandy.[1]

The spoor of this floating ice has been followed still ther east, erratics from Brittany and Normandy occurring mmonly in the 'diluvial' gravels of Belgium and Southern olland up to a height of 360 ft. above the sea. The same avels contain a curious commingling of stones, derived m the Vosges, the Ardennes, &c., and from Scandinavia. iese deposits form the 'diluvium entremêlé' of Dr. A. ens. When the Scandinavian inland ice advanced into e Netherlands, a large part of Belgium and the adjacent rts of Holland were covered by the waters of an mense lake. Into this lake, according to Dr. Erens, bergs shed from the northern *mer de glace* dropped Scanavian erratics, which were thus commingled with detritus ought down by the rivers flowing from the south. At at time England was still united to the Continent across hat are now the Straits of Dover. Eventually, however, e connecting isthmus was cut across by the waters caping from the great glacial lake, which thus in time me to form a gulf of the sea. The Straits, widened by arine erosion and by that depression of the coast-lands to hich the old raised beaches testify, were then entered by ating ice coming from the shores of Brittany and from e flooded rivers of Northern France. It is thus, according Dr. Erens, that erratics from the Morvan, from Brittany d Normandy are now found associated in the diluvial avels of Belgium with rock-fragments derived from andinavia, and from the Vosges and the Rhine-lands.[2]

Thus in Northern France and Belgium, as in Southern ngland, we have evidence of cold climatic conditions having

[1] *Compt.-rend. hebd. des Séances de l'Acad. des Sciences*, 1886, t. cii. p. 86; *Bull. de la Soc. géol. de France*, 3e Sér. t. xiv. (1886) p. 569.

[2] *Archives du Musée Teyler*, Sér. ii. t. iv. (1893) p. 1.

obtained during the Glacial Period. Nor is this all, for the testimony of the raised beaches of the French coast is of like import with that of the raised beaches on the English side of the Channel. Thus we have evidence (1st) of a time when the land stood at a somewhat lower level than now, and when floating ice distributed erratics along the coasts; (2nd) of a time when the climate became temperate and the scattering of erratics by shore-ice ceased; (3rd) of a time when the sea retreated to a lower level, and when eventually cold conditions returned and sheets of rubble-drift gradually overspread the land.

CHAPTER XXXVI.

THE GLACIAL SUCCESSION IN EUROPE.

ıcial times—First glacial and interglacial epochs—Second glacial and terglacial epochs—Third glacial and interglacial epochs—Fourth glacial d interglacial epochs—Fifth glacial and interglacial epochs—Last traces glacial conditions, and passage to the present—Tabular statements of ıcial succession.

E have now completed our review of the glacial phenomena of Europe, and have learned that in all the ›ns critically examined the evidence points to periodicity acial action. It can no longer be maintained that the Age was one continuous epoch of cold climatic conditions. testimony against this old view has been set forth at length in preceding chapters, but not in such detail as ›uld have wished. The exigencies of space, however, ent fuller treatment, and have compelled me to leave uched much interesting evidence. The literature of the ect has grown to such an extent, indeed, that it is hopein a general treatise to do more than sample it. Neveress, the outlines I have traced may serve to give a not equate conception of the main features of glacial history, it is with these that this work is mainly concerned. To ›le the reader to follow the argument maintained in the succeeding chapters, it may be well to present at this a short summary of the results at which we have now 'ed. In this summary I shall take into consideration the leading facts that bear upon the question of the al succession in Europe.

. PREGLACIAL TIMES.[1]—The earliest indications of the oaching Ice Age are met with in the marine deposits

[1] 'he general reader will quite understand what is meant by the term acial,' but I ought to mention that it has been applied by geologists to ı deposits which underlie the 'lower boulder-clay' of the regions in these deposits occur. But, as we have learned, many accumulations of

of the Pliocene system. The older Pliocene deposits introduce us to a time when the waters of the North Sea were tenanted by a fauna which is clearly indicative of genial climatic conditions. And similar testimony to the warmth of the period is furnished by the contemporaneous marine lacustrine and terrestrial accumulations of other regions of Europe. In those days the sea occupied considerable tracts in the east and south of England, in Belgium, Holland, Northern and Western France, and the coast-lands of the Mediterranean. As time rolled on, however, the genial conditions gradually passed away. The southern forms slowly retreated from the North Sea, while at the same time northern and boreal types came to occupy their place. Similar migrations were in progress farther south, many British and boreal forms finding their way into the Mediterranean. Upon the land like changes were brought about—the luxuriant flora and the great mammals of the Pliocene retreating gradually before the approaching winter of the Glacial Period.

II. First Glacial Epoch.—Eventually a thoroughly arctic fauna lived in the North Sea. Great snow-fields at the same time came into existence, and a gigantic glacier occupied the basin of the Baltic.[1] The mountainous parts of the British Islands, we can hardly doubt, must likewise have been ice-clad, but of this there is no direct evidence. Farther south the Alpine Lands were swathed in snow and ice, and great glaciers occupied all the mountain-valleys and piled up their terminal moraines upon the low-grounds at the foot of the chain. In Central France very considerable glaciers also descended from the great volcanic cones of Auvergne and Cantal, and deployed upon the plateaux. And probably in many other mountain-districts similar conditions obtained.

so-called 'lower boulder-clay' are not the products of the earliest epoch of glaciation, and the fossiliferous beds which sometimes underlie them are, therefore, not necessarily of preglacial age. I apply the term exclusively to deposits which were laid down before the earliest appearance of glacial conditions in temperate latitudes. These, so far as our present knowledge goes, are the only accumulations which we are justified in classing as preglacial.

[1] The limits reached by this earliest 'great Baltic glacier' are not known. In Southern Sweden, however, it occupied a wider area than the great Baltic glacier of the fourth glacial epoch, its northern limits lying at least thirty miles farther north than those reached by the latter.

III. FIRST INTERGLACIAL EPOCH.—Eventually cold con-
ons passed away. The arctic fauna retreated from the
rth Sea, and at the same time dry land occupied the
ithern part of that sea up to the latitude of Norfolk at
st. Across this new-born land flowed the Rhine and
er rivers. A temperate flora, comparable to that now
sting in England, clothed the land in our latitude, while
hippopotamus, elephants, deer, and other mammals
ame denizens of our country. In other parts of Europe
ilar genial conditions obtained—conditions which, to
ge from the flora, were even more genial than are now
erienced in the same regions. A luxuriant deciduous
a occupied the valleys of the Alps, and flourished at
ghts which it no longer attains. That flora was accom-
ied by a mammalian fauna (North Italy) which embraced
ong other forms *Elephas meridionalis*. From the amount
iver-erosion effected during this epoch we may gather
t the stage was one of long duration. By-and-by, how-
r, cold conditions again supervened—the temperate flora
ppeared from England, and was gradually replaced by
tic forms.

IV. SECOND GLACIAL EPOCH.—The appearance of that
tic flora and the immigration into the North Sea of arctic
lluscs heralded the approach of the greatest of the
ropean ice-sheets. This enormous *mer de glace* covered
the northern part of the Continent and flowed south into
xony. At the same time the Alpine glaciers reached their
atest extension, while in all the other mountains of
rope snow-fields and glaciers made their appearance. In
raglacial tracts, as in Southern England and Northern
ance, and in many other regions, the formation of rock-
ble was in active progress, and much movement of such
erficial accumulations took place. These physical
inges were necessarily accompanied by great migrations of
ra and fauna—arctic-alpine plants coming to occupy the
-grounds of Central Europe, and northern animals ranging
wn to the shores of the Mediterranean.

V. SECOND INTERGLACIAL EPOCH.—The enormous mo-
nic accumulations and fluvio-glacial gravels of the second
cial epoch are sufficient evidence of its prolonged duration.

Eventually, however, it passed away and the climate by degrees became temperate and even genial. The arctic-alpine flora and northern fauna retreated from the low-grounds and were replaced by temperate and southern forms. The character of the plants which then occupied North Germany and Central Russia is suggestive of a milder and less extreme climate than is now experienced in those regions —and the mammalian fauna of the epoch, which included the hippopotamus and *Elephas antiquus*, was in keeping with the flora. Britain would appear to have been connected with the Continent at this time, and land-passages probably joined our Continent to North Africa. Again, however, the climate began to deteriorate, accompanied by renewed migrations of flora and fauna, and as the third glacial epoch approached much low-lying land in Northern and North-western Europe was submerged. The long duration of this interglacial phase is shown by the great depths to which the rivers of the epoch succeeded in eroding their valleys.

VI. THIRD GLACIAL EPOCH.—At the climax of this epoch a most extensive ice-sheet again overwhelmed the major portion of the British Isles and a vast area of the Continent. It did not, however, attain the dimensions of its predecessor. From the Alps great glaciers again descended to the low-grounds, where they dropped the terminal moraines of the 'inner zone.' These moraines form most conspicuous objects, and extend in curving lines between the highly denuded moraines of the first and second glacial epochs. Like these they are accompanied by well-marked sheets and terraces of fluvio-glacial gravels. Many of the other mountains of Europe were similarly snow-clad and glaciated, while rubble-drifts accumulated in extraglacial regions.

VII. THIRD INTERGLACIAL EPOCH.—The third glacial epoch eventually passed away like its predecessors and was gradually succeeded by temperate conditions. Of this change the most direct evidence we have is that furnished by the youngest interglacial beds of the Baltic coast-lands. It is probable, however, that a considerable proportion of the old alluvial deposits of Britain and Ireland, which have hitherto been classed as of postglacial age, really belong to this interglacial epoch. Amongst these are the clays, &c., with

Irish deer, red-deer, &c., which underlie the older peat-bogs. In the Baltic area the interglacial beds contain in some places arctic forms, in others a temperate marine fauna, in yet others they have yielded mammoth, woolly rhinoceros, horse, Irish deer, and urus. It is obvious that these beds cannot be strictly contemporaneous. Some probably belong to the beginning, others to the middle of the third interglacial epoch, while others again may pertain to its close. They show us clearly, however, that after the disappearance of glacial conditions the Baltic became tenanted by a temperate North Sea fauna, while the adjacent lands supported a corresponding terrestrial fauna and flora.

VIII. Fourth Glacial Epoch.—In the early stages of this epoch the low-grounds of Scotland were submerged to the extent of 100 ft. at least, while an arctic marine fauna lived round the coasts. Eventually the various mountain-districts of our islands were cased in snow and ice, large glaciers filling all the Highland fiords and calving their icebergs in the sea—a condition of things implying a snow-line not exceeding 1,000 to 1,600 ft. in elevation. But the greatest development of ice was witnessed in the Baltic area. The Scandinavian peninsula once more supported an ice-sheet that broke away in icebergs at the mouths of all the fiords of Western Norway. Finland was well-nigh overwhelmed, while the Baltic basin was occupied by a great ice-stream which invaded North Germany and Denmark. Later on, as the ice-sheet melted away, a wide area in Scandinavia was submerged in a cold sea which communicated widely with the Baltic. In the Alps large glaciers flowed for long distances down the great valleys, but came far short of attaining the dimensions reached by those of the preceding glacial epoch. At the same time small local glaciers appeared in the high valleys of some of the mountain-ranges of Middle Europe.

IX. Fourth Interglacial Epoch.—At the climax of this epoch temperate conditions prevailed, and extensive forests of deciduous trees spread far north into regions where such trees no longer flourish. The British Isles now formed part of the Continent. The cold sea had retreated from Scandinavia, and the Baltic was converted into a great lake. Eventually, however, submergence again ensued, but the sea,

which now invaded Scandinavia and communicated with the Baltic, was tenanted by a fauna indicative of more genial conditions than obtain at present.

X. Fifth Glacial Epoch.—This epoch is characteristically represented by local or valley-moraines in the British Isles, the position of which indicates that the snow-line reached in Scotland an average height of 2,500 ft. The disappearance of the genial conditions of the preceding temperate epoch was marked by the submergence of the Scottish coast-lands to a depth of about fifty feet below their present level. Here and there in the north-west of Scotland glaciers reached the sea and dropped their moraines on the beaches of the period. To the same epoch may be assigned the formation of most of the corrie rock-basins of the British Isles—each of these basins marking the site of a glacier of more or less limited size. The submergence in Scotland probably commenced in the preceding temperate epoch, as it did likewise in Scandinavia. In the Alps the fifth glacial epoch is marked by the moraines of the so-called 'second postglacial stage'—moraines that indicate a renewed advance of the glaciers of that region.

XI. Fifth Interglacial Epoch.—This epoch was heralded by the re-emergence of the land and the retreat of our valley-glaciers. Again the British area attained a wider extent than at present, but we cannot tell whether it became united to the Continent. The upper 'buried forests' in the peat-bogs of North-west Europe show that this epoch was characterised by drier conditions and a remarkable recrudescence of forest-growth—conditions recalling those of the preceding interglacial epoch.

XII. Sixth Glacial Epoch.—To this epoch belong our latest raised-beaches, which indicate a limited submergence not exceeding, in Scotland, twenty to thirty feet. The climate once more became humid and less favourable to forest-growth. Hence forests decayed while peat-bogs extended their area. The snow-line stood at an elevation in Scotland of 3,500 ft.—and thus nourished a few small glaciers in our loftiest mountain-groups.

XIII. The Present.—Marked in Britain by the retreat of the sea to its present level, and by the return of milder

conditions and the final disappearance of per-
iow-fields.

l be observed that in this short résumé I have from the use of the term 'postglacial.' The word applied to deposits of such widely different ages ,s ceased to be of any value for classificatory From late Pliocene down to the close of Pleis-
ies we have the record of a continuous series of ;al and climatic changes. Early in the cycle the d interglacial phases attained their extreme de-
. The climax once passed, each successive cold epoch declined in importance. In a word, the ,nd geographical changes became less and less the cycle drew to a close. From the point of ie present it seems absurd to speak of 'fifth' and icial epochs, seeing that these epochs were marked e presence in Britain of limited snow-fields and glaciers. When either of these epochs is con-
th the conditions that obtained in early glacial y would seem to be more properly described as epochs. But they undoubtedly belong to one and series of alternating cold and genial conditions, this larger point of view cannot be designated than glacial.

following tabular statements the glacial and inter-
;ession is given in ascending order, beginning with beds—the successive stages being indicated in the ıles by the same numbers.

GLACIAL SUCCESSION IN BRITISH ISLES.

ırn crag and Chillesford	1. Marine deposits with pronounced arctic fauna.
ɔed of Cromer.	2. Temperate flora; *Elephas meridionalis*, *E. antiquus*, *Rhinoceros etruscus*, *Hippopotamus*, &c.
boulder-clays and asso- ;lacial deposits.	3. Ground-moraines, &c., of most extensive ice-sheet.
fresh-water, and terres- ations; basin of Moray of Irish Sea; Lanark- 'e, Edinburghshire, &c.; ; Sussex beach-deposits, ave, &c.	4. Northern and temperate flora and fauna; *Elephas primigenius*, *Rhinoceros tichorhinus*; reindeer, &c.; hippopotamus, *Elephas antiquus*, *Rhinoceros leptorhinus*, Irish deer, grisly bear, lion, hyæna, &c.
boulder-clay and asso- lacial deposits.	5. Ground-moraine of ice-sheet which extended south to the Midlands of England.

GLACIAL SUCCESSION IN BRITISH ISLES—*continued.*

6. Fresh-water alluvia underlying oldest peat-bogs; probably a considerable proportion of our so-called 'post-glacial' alluvia.	6. Temperate flora and fauna; Irish deer, red deer, *Bos primigenius*, &c.
7. Boulder-clays and terminal moraines of mountain-regions; 100-ft. beach of Scotland; arctic plant-beds.	7. Morainic accumulations of district- and large valley-glaciers; arctic marine fauna; snow-line at 1,000 to 1,600 ft.; arctic flora.
8. Lower buried forest.	8. Temperate flora and fauna.
9. Peat overlying 'lower buried forest'; Carse-clays and raised beaches; valley-moraines; corrie-moraines.	9. Small glaciers in mountain-regions; snow-line at 2,400 to 2,500 ft.
10. Upper buried forest.	10. Temperate flora and fauna.
11. Peat overlying 'upper buried forest'; low-level raised beaches; high-level valley-moraines and corrie-moraines.	11. Small glaciers in the most elevated regions; snow-line at 3,500 ft.

GLACIAL SUCCESSION IN NORTHERN EUROPE.

1. Lowest boulder-clay of Baltic coast-lands.	1. Ground-moraine of earliest Baltic glacier.
2. Alluvia underlying lower diluvium of Hanover, Brandenburg, &c.	2. Temperate flora and fauna, including *Cervus elaphus*, *C. capreolus*, *Bos*, sp., *Rhinoceros*, sp., &c.
3. Lower diluvium of Central and Southern Germany, Holland, Central Russia.	3. Ground-moraines, &c., of most extensive *mer de glace*.
4. Fresh-water and marine deposits of Baltic coast-lands, Grünenthal, Rixdorf, Kottbus, Moscow, &c.	4. Northern and temperate floras and faunas; mammoth, *Elephas antiquus*, Irish deer, horse, &c.
5. Upper diluvium of Central Germany, Poland, West Central Russia; second boulder-clay of Baltic coast-lands.	5. Ground-moraines, &c., of ice-sheet which flowed some 40 or 50 miles south of Berlin.
6. Fresh-water and marine deposits of Baltic coast-lands.	6. Northern and temperate floras and faunas.
7. Youngest boulder-clay of Baltic coast-lands; terminal moraines in South Norway and Sweden, Baltic Ridge, and Finland. Arctic plants under oldest peat-bogs of Denmark, Norway, Sweden, &c.; *Yoldia*-clays, &c.	7. Accumulations of last great Baltic glacier; submergence in Scandinavia; adjacent lands clothed with arctic flora.
8. *Ancylus*-beds of Baltic area; older buried forests generally; *Littorina*-beds of Baltic area in part.	8. Temperate flora and fauna; climate at climax of stage more continental than now; conditions becoming more humid in later stages.
9. Peat overlying older buried forests; calcareous tufas, &c.; *Littorina*-beds in part; large valley-moraines in Norway.	9. Humid climate; glaciers here and there reach heads of fiords.
10. Younger buried forests.	10. Temperate flora and fauna; drier conditions.
11. Peat overlying younger buried forests; high-level terminal moraines in Norway.	11. Humid climate; relatively small glaciers.

GLACIAL SUCCESSION IN CENTRAL AND SOUTHERN EUROPE.

west ground-moraines; ter- oraines opposite mouths of leys; plateau-gravels (Alpine Oldest morainic accumula- Central France (?).	1. Accumulations of first glacial epoch.
tting breccia; lignites of ; so-called Upper Pliocene f Central France.	2. Flora indicates warmer conditions than now obtain in those regions; *Elephas meridionalis*, *Rhinoceros leptorhinus*, &c.; valleys deeply eroded.
ound-moraines; terminal mo- outer zone; high-level gravel (Alpine Lands); 'Ceppo' of ly; Pleistocene conglomerate ian coast-lands; torrential rraces of South-west Italy; of raised beaches (France); raines of Urals, Carpathians, intains of Central Europe; l France, Pyrenees, Corsica, s, Balkan Peninsula, &c.; eccias of Gibraltar; and ift, in part, of other regions.	3. Accumulations of epoch of maximum glaciation.
nites of Switzerland, Ba- ; alluvial deposits; beach tions underlying rubble-drift France); terraces cut in ccias of Gibraltar.	4. Temperate flora; *Elephas primigenius*, *E. antiquus*, *Rhinoceros Merckii*, *Bos primigenius*, *Cervus elaphus*, &c.; valleys deeply eroded.
ound-moraines; terminal mo- inner zone; low-level gravel (Alpine Lands); valley-mo- other mountain-regions; ifts in part.	5. Accumulations of third glacial epoch.
uvial deposits, &c. (?).	6. Not yet recognised,
rminal moraines in large nal valleys of the Alps; small oraines in the higher valleys mountain-regions.	7. Accumulations of fourth glacial epoch = 'first postglacial stage' of glaciation.
uvial deposits, &c. (?).	8. Not yet recognised.
rminal moraines in higher f Central Alps.	9. Accumulations of fifth glacial epoch = 'second postglacial stage' of glaciation.
lluvial deposits, &c.	10. } Not recognised.
igh-level moraines in West-	11. }

CHAPTER XXXVII.

CAVE-DEPOSITS AND 'VALLEY-DRIFTS.'

Prehistoric deposits—Stone, Bronze, and Iron Ages—Palæolithic or Old Stone Period—Neolithic or New Stone Period—Universal distribution throughout the British Islands of Neolithic implements—Animal remains associated with Neolithic relics—Palæolithic implements—Caves and cave-deposits—Kent's cavern, Torquay—Succession of deposits—Cave-deposits of the Continent—M. Boule on French cave-deposits—Palæolithic epochs of M. Mortillet—Break between Palæolithic and Neolithic times—River-gravels, &c., with mammalian remains and Palæolithic implements—M. Ladrière's researches—Valley-drifts of Northern France—Valley-drifts of the Thames—General features and succession of deposits—Climate of Palæolithic times—Relation of cave-deposits and valley-drifts of Britain to glacial and interglacial series.

A FASCINATION attaches to the early history of every people. We long to penetrate that mystery which the lapse of ages has drawn like a thick curtain round the cradle of our race. How eagerly do we scan the oldest written records that have any reference to our country and its people; and how assiduously do we try to shape a coherent story out of those vague myths, legends, and traditions which have come down to us from the long-forgotten past! But there are memorials of Man in this, as in other countries, which date back to so remote a period than even the oldest traditions have nothing whatever to say about them. The English historian begins his narrative with the Roman invasion, and the archæologist until recent years could hardly trace the story farther back; but now he can tell us of a time far beyond the first dim beginnings of history and tradition, when races of savage men and tribes of wild animals, some of which have long been extinct, were denizens of Britain. Hitherto we had been taught to look upon Stonehenge and the so-called Druid-circles as the oldest

norials of Man in this country—mysterious monuments nging to the shadowy past, about whose age and uses vague conjectures could be offered. If older races than builders of Stonehenge ever lived in Britain we knew ing, and could hardly hope to know anything, about n. The past was apparently separated from us by a gulf h it was vain to think that any ingenuity would succeed ridging over.

Now all this is changed. The massive monoliths of iehenge, however venerable their antiquity, seem but as ctures of yesterday; the standing-stones of Avebury, of ernish, and Stennis, the so-called vitrified forts, the round ers of Ireland, and all those remains of ancient camps, llings, and burial-places so abundantly met with through- the British Islands, are of immeasurably more recent than certain rude stone implements which our cave- osits and ancient river-gravels have yielded. Since nehenge rose upon Salisbury plains no great change in physical geography of Britain has taken place. The ruction of ancient forests and the cultivation of the soil e doubtless in some measure altered the aspect of the l and influenced the character of the climate. Our hills valleys, however, we are sure have remained the same, even the coast-line has experienced probably little change. nges undoubtedly there have been, yet none so consider- as to invalidate the truth of the statement, that since days of the builders of Stonehenge no great geological lution has taken place in Britain. But the rude stone lements to which I have referred date back to a period n the appearance presented by our country differed tly from the present; and for so long a time did the old es who used these rude implements occupy the British , that the slowly-acting forces of Nature were enabled, ng that time, to bring about many geological changes, of which required ages for its evolution.

What, then, is the nature of that evidence which has ghed with archæologists and geologists in assigning to n this great antiquity? It would lead me far beyond the its I have set for myself were I here to attempt anything a detailed account of the archæological evidence. My

object will be sufficiently served if I give only a brief outline of the general results.[1]

All those monuments and memorials of Man which belong to prehistoric times have been arranged by archæologists under three groups. The classification adopted is based chiefly upon the distinguishing features presented by such objects of workmanship as weapons, implements, and personal ornaments. The oldest group comprises implements of *stone*; next in order come *bronze* relics; and these are succeeded by tools and weapons of *iron*. The articles of stone indicate upon the whole a much lower grade of development than those of metal, and hence archæologists have inferred that the races who used stone-knives, hatchets, and hammers preceded in time those to whom the use of metal was known. In like manner they have argued that cutting-tools and weapons of bronze were supplanted by weapons of iron—the use of iron for such purposes evincing more knowledge of the metals and a greater advance in civilisation. Hence it is customary to speak of the Stone Age, the Bronze Age, and the Iron Age.

Geological investigations have strongly supported this classification—deposits containing the stone implements having been proved in many ways to be older than those which have yielded relics of bronze, just as these latter have been shown to belong as a whole to an older period than weapons and tools of iron. But while we speak of these three ages it must be distinctly understood that they are not separated from each other by any hard and fast line. The manufacture of stone tools and weapons did not die out all of a sudden, and the employment of bronze immediately succeed. On the contrary, stone hammers and implements continued in some use long after bronze had been introduced, just as this latter certainly found favour and was extensively employed, especially for ornamental purposes, after the advantages of iron for knives and swords had become recognised.

With the Bronze and Iron Ages, however, the geologist

[1] The reader who desires fuller information must consult Sir J. Lubbock's *Prehistoric Times*, and Sir John Evans's *Ancient Stone Implements of Great Britain*; see also Mr. W. G. Smith's *Man, the Primeval Savage*.

›er has comparatively little to do: although, did space ›it, it could be shown that even in regard to the history ›ese two ages, he might have something not uninteresting ›ay. But, as I have already remarked, the physical ›ges which have supervened since the beginning of the ›ize Age sink into insignificance before those which can be ›n to have taken place during the preceding Stone Age. to the relics of this latter age, then, and the lessons ›h these seem to teach, that I wish now to direct ›tion.

The Stone Age is subdivided into two periods, which are ›ed respectively the Neolithic or New Stone epoch, and Palæolithic or Old Stone epoch. To the former belong ›e implements and weapons which are often ground at edges, and more or less polished and finely finished, and ›h in variety of form and frequent elegance of design ce no inconsiderable skill on the part of the old workmen. The implements and weapons belonging to the older or ›olithic epoch are never ground at the edge or polished, are merely chipped into shape. Many are extremely in form and finish, while others are less so, and ›oximate in character to certain of the simpler Neolithic s. Some archæologists, indeed, believe that between the st Palæolithic and the more finished Neolithic imple- ts they can distinguish a series of intermediate forms, ›h would seem to indicate a gradual transition from the Stone into the New Stone epoch. But the so-called ›mediate (Mesolithic) types generally occur in positions ›h are indicative of a much greater antiquity than can be ›ned to the implements known as Neolithic. Moreover, ›e the latter are scattered broadcast over the British Isles, former have hitherto been met with only in the south of ›land. Although it may be true, therefore, that certain ›e later Palæolithic implements approximate in character ›me of the ruder Neolithic forms, so that in the case of ›vidual specimens it may sometimes be hard to say ›ther they should be referred to the Old Stone or to the › Stone Age; still, as we shall find, there is strong ›pendent evidence to show that a hiatus or gap separates ›e two ages in North-western Europe.

Incidental reference has already been made to the occurrence of Palæolithic implements in deposits of glacial age. They have likewise frequently been discovered in cave-accumulations and in certain river-gravels which are of relatively great antiquity. It will be well, therefore, to glance briefly at the evidence referred to.

In the limestone districts of England caverns more or less abound. These remarkable cavities are formed by the slow percolation through the rock of acidulated water in the following manner. Rain-water absorbs carbonic acid from the atmosphere, and, after passing over and sinking through the soil, always takes up more, which it derives from decaying organic matter. Thus acidulated, it soaks downward through the rock by natural cracks and fissures, the walls of which it gradually dissolves, and eventually makes its exit at some lower level as a spring or springs of *hard* water. In the course of long ages this constant circulation of rain-water and springs, and consequent waste of limestone, result in the formation of caves and winding galleries, through which very frequently considerable streams have found their way as underground rivers. Thus, both by chemical action and by the wear and tear of aqueous erosion, these subterranean galleries and caves have been gradually widened and deepened. When traced from lower to higher levels they prove in not a few cases to have once communicated with the upper surface by wide apertures, formed either by the falling-in of the roof or by the water eating along some natural fissure. Many of these apertures, however, are now closed up with calcareous matter and heterogeneous débris.

After streams had flowed in such underground channels for a longer or shorter time, they were often at last compelled to abandon them, either owing to one or other of the many changes which the subterranean forces have brought about, or to some local shifting of the subaërial part of their course, such as frequently happens during heavy floods. Caves which were in this way deserted naturally became the dens of wild beasts or the abodes of savage men.

Thus in the phenomena of the English caves we have, as Sir Charles Lyell pointed out, the following succession of changes:—1st, a period when the caves and tortuous

ɜries were licked out by the percolation of acidulated ɜr; 2nd, a time when these hollows became the channels ngulphed streams; and, 3rd, a period when these streams ppeared, and the caves were occupied by wild beasts and ı, whose remains are found commingled upon the floors he caverns.

Let us now shortly examine the mode in which such ains occur. For this purpose it will be sufficient to ct one example, as this may be considered typical of all others. Our specimen cave is the famous Kent's Cavern r Torquay, which has been systematically searched under direction of a committee of the British Association, the ıils of the investigation having been from time to time ımunicated by the late Mr. Pengelly, who personally erintended the operations.[1]

The deposits met with upon the floor of the cave are ɜn in descending order as follows:—

. Large blocks of limestone, sometimes cemented together by stalagmite.
. A layer of black muddy mould, three inches to twelve inches in thick-
.
'. Granular stalagmite sixteen inches to twenty inches thick, reaching five in part, almost continuous, containing large fragments of limestone, a an jaw, and remains of bear, elephant, rhinoceros, hyæna, horse, fox, &c.
:. Black band, four inches thick, composed mostly of small fragments of red wood; occurred only in one part of the cave.
ı. Red cave-earth, varying in thickness, and containing 50 per cent. of ılar fragments of limestone, with bones and teeth of lion, bear, mammoth, oceros, hyæna, reindeer, Irish deer, red deer, wolf, &c., and many human lements. Excavated to a depth of four feet.
ı. Crystalline stalagmite, in places twelve feet thick, with bones of the cave-
.
'. Breccia and red loam, with remains of the cave-bear and some rude ements of flint and chert.

The large blocks of limestone that cumber the floor of the ern have of course fallen from the roof. The layer of ɜk muddy mould which immediately underlies them has ded portions of the human skeleton, along with fragments pottery and articles of stone and bronze. Besides these re also occur bones of deer, oxen, sheep, pig, and other nals which are still indigenous to the country. There is hing, therefore, to indicate that this upper deposit is of

Full details are given in Mr. Pengelly's interesting yearly reports, *Brit. Rep.*, beginning in 1865; the same geologist gives an admirable summary he evidence in a lecture to the working-classes at Manchester; see also ıns's *Ancient Stone Implements* and Lyell's *Antiquity of Man*.

great antiquity; some of the remains indeed appear to belong to Romano-British times.

The black mould rests upon a pavement of stalagmite—a deposit which is formed by the drip of water holding carbonate of lime in solution. The accumulation of this deposit must in most cases be a very slow process, nor are we in much danger of over-estimating the time required for the growth of the stalagmite in Kent's Cave. A solid cake of stalagmite, varying in thickness from one inch to five feet, and almost continuous over the whole floor of this extensive cave, implies the lapse of a very long time. We have to conceive of it forming gradually, as drop after drop of lime-water fell from the roof and evaporated upon the floor. Nor was its accumulation at all likely to have been continuous: sometimes the drip would be in one place, sometimes in another; and indeed portions of the roof and floor might remain dry during lengthened periods. One may gather some notion of the time required to form a layer of stalagmite five feet thick when he reflects that some two thousand years have elapsed since the Romano-British remains were left upon the floor of the cave, and that in all that time the deposition of stalagmite has been very partial—many parts being quite free from it, while where thickest it does not exceed six inches; in fact the deposit occurs only in patches.[1]

The 'black band' obviously marks the site of an old hearth. The underlying deposit is a mass of red earth or loam, of irregular thickness. It has not been excavated to a greater depth than four feet. The origin of this earth is not far to seek. In all countries where limestone occupies the surface we find just such an earth forming the subsoil. Rain, as we have seen, dissolves the limestone, which, however, is not a pure carbonate of lime, but always contains a larger or smaller percentage of insoluble matter. While the carbonate is carried away in solution, therefore, the impurities are left behind and in course of time may accumulate so as to form

[1] Of course, the rate at which stalagmite forms depends almost entirely on the quantity of acidulated water passing through the rock. In some caves the rate will be excessive; in others again it will be very slow. Hence, even if we ascertained the rate at which the stalagmite increased in one particular cave, that would give us no criterion by which to estimate the time required for the growth of stalagmite in any other cave, for the conditions in separate caves are never likely to be precisely the same.

irregular layer of considerable thickness. Such, for nple, is the origin of the red earth with flints, which is overlying the chalk in the south-east of England. The earth met with in caves has doubtless been introduced ı above by rain and melting snow, making their way n from the surface by fissures and other openings. Both 'granular stalagmite' and 'cave-earth' have yielded e quantities of bones and teeth of extinct, or no longer genous, mammalia, commingled with which are numerous lements of flint and some of horn, 'presenting,' as Pengelly has said, 'a character so humble and so little ed as to betoken a very low type of civilisation.'

Scattered throughout all the accumulations, in stalagmite earth alike, occur many fragments of limestone, similar hose associated with the black mould.

Underneath the cave-earth in certain parts a lower bed talagmite appears, which reaches in places the great thicks of twelve feet. This ancient deposit rests upon a breccia, which extremely rude human implements and numerous ains of the cave-bear have been found. When one ects on the length of time required for the formation of lve feet of stalagmite, the great antiquity of these lower osits cannot fail to astonish him.

According to Mr. Pengelly, the men whose relics are met ı in the black band and cave-earth were farther advanced ı the savages whose implements occur in the old breccia. former 'made bone tools and ornaments, harpoons for uring fish, eyed bodkins for stitching skins together, awls haps to facilitate the passage of the slender needle through tough thick hides, pins for fastening the skins they wore, perforated badgers' teeth for necklaces or bracelets.' hing of this kind is met with in the breccia; the only lements found at that low level being of a much ruder racter.

There are many interesting questions suggested by the arkable commingling of mammalian remains in these accumulations, but I shall reserve for the present t I have to say upon this subject. Meanwhile the ons we learn from the English caves would appear to be e:—

1st. That Man and certain locally or altogether extinct animals co-existed in England at some remote period.

2nd. That the long duration of this period is shown by the thickness of the stalagmitic pavements, which rest upon and are intercalated with the cave-earth; and by the evidence of drip, which is more or less conspicuous all through the cave-earth itself.

3rd. That after having occupied the English caves for untold ages Palæolitic Man disappeared for ever, and with him vanished many animals now either locally or wholly extinct.

4th. That the deposits immediately overlying the granular stalagmite contain a very different assemblage of animal remains, along with relics of later prehistoric and historic times.

5th. That there is no passage, but on the contrary a sharp and abrupt break, between these later deposits and the underlying Palæolithic accumulations.

Speaking in general terms, one may say that the cave-deposits of the Continent yield evidence similar in character to that presented by the corresponding accumulations in this country. My limits will not allow me to give any details of the results obtained from the caves of Belgium, France, Germany, Italy, and other lands. But some of the established conclusions may be shortly referred to. In the first place, then, it has been demonstrated that the Palæolithic age was one of prolonged duration. This is shown by the thickness of the stalagmitic pavements which, even on the assumption of an abnormally rapid rate of accretion, must yet have taken very many years to accumulate. Moreover, there is evidence in some cases to prove that stalagmitic pavements have been broken up and the underlying deposits removed in whole or in part by running water in Palæolithic times. The series of accumulations covering the floor of a cave is, therefore, not always complete. Breaks in the succession now and again occur—showing that epochs of slow accumulation of stalagmite and cave-earth have been interrupted by epochs of erosion and partial re-arrangement of materials. Occasionally beds of gravel, sand, and silt are met with at the very base of the deposits, and these water-

ıed beds sometimes contain mammalian remains and implements, although they are more usually barren of ls. The presence of such accumulations shows that ıing water, probably in most cases the stream of the adıt valley, now and again entered the cave. The overlying , consisting of cave-earth and stalagmite, demonstrate a time came when the stream had excavated its valley ıch a depth that it could no longer reach the entrance ıe cave, even during the highest floods. The larger ber of caves, however, contain no fluviatile deposits ıy kind. The two most prominent and characteristic mulations are stalagmite and 'earth'—both of them lly enclosing angular fragments and blocks of limestone, h have fallen from time to time from the roof and s. The mammalian remains and human implements met with in stalagmite and earth alike. Obviously have been covered up just where they were left on floor of the cave—by the drip from the roof and the sional intrusion of rain-wash. Many of the bones and ı have a highly-bleached and corroded appearance, as if had been exposed for a long time to the action of the her. These facts show that the cave-earths have not introduced, as was at one time supposed, by floods and ial waters. No one has pointed this out more clearly M. Boule, who has personally examined many of the ch caves.[1] Amongst other caves referred to by this llent observer is that of Roussignol, near Reilhac, in the e of the limestone-plateau of Gramat, which extends een the Dordogne and the Lot. The surface of this n is almost entirely bare of soil, the insoluble residue ne calcareous rocks accumulating only in clefts and pt depressions into which it is swept by the rains. The e region is fissured and pierced by 'swallow-holes,' h have been gradually formed by the action of acidu- water descending through cracks from the surface. ı swallow-holes naturally communicate with the deserted ses of underground streams or caves. The Cave of ıac, then, is simply a rather larger cave than some of other underground fissures in its neighbourhood, and,

[1] 'Notes sur le Remplissage des Cavernes,' *L'Anthropologie*, 1892.

like these, it has communications with the surface. The interior is filled with a red compact clay, crowded with angular blocks and fragments of limestone and with mammalian remains in different states of preservation. The upper part of this cave-earth is traversed by the old hearths where Palæolithic Man cooked his food. Lower down in the clay there is no trace of human occupation, but numerous broken, split, and abraded bones occur—which have all the appearance of having been exposed for a longer or shorter time to the action of the atmosphere. That the 'earth' could not have been introduced by river-floods of any kind is sufficiently shown by the fact that the cave is quite beyond the reach of the nearest stream, which flows at a level of nearly 700 ft. lower down. Before the cave could be flooded by any river-inundation, the whole plateau must needs have been under water. But there is no necessity for this extravagant supposition. M. Boule shows that the cave-earth is identically the same as the red earth that occurs in the superficial hollows of the plateau. Chemical analyses have shown that there is no difference between them. He concludes, therefore, that the filling of the cave has been effected from above at the expense of the superficial red earth of the plateau. It is unnecessary to go into details, but M. Boule's observations show quite clearly that the earth has been introduced by various fissures and openings, the directions taken by the invading rain-wash being readily traced.[1] In the dry parts of the cave no fissures open upwards, and only the meagrest deposit of cave-earth appears. The stalagmites of the cave I need not refer to; they tell the same tale as similar deposits everywhere. The filling up of the cave was only gradually effected. As M. Boule points out, it continued during the whole time it was occupied by Palæolithic Man, and long after he had taken his departure. Doubtless during heavy rains and the melting of snow, the introduction of earth would now and again be comparatively rapid. It was probably at such seasons that

[1] The late Mr. S. V. Wood held similar views as to the origin of the amorphous cave-earth, which he thought was an atmospheric formation which in the state of mud or sludge was subsequently introduced by fissures into the caves, carrying with it the remains of animals from the surface (*Quart. Journ. Geol. Soc.* 1882, p. 719).

weather-worn and abraded bones and some of the
ular fragments of limestone were brought into the caves.
: abraded bones are the less readily destroyed portions of
.etons, which may originally have lain at the surface, and,
:ther with other superficial débris, would readily be swept
y by torrential rains into the swallow-holes and pipes
t communicated with the caves below.

Another interesting conclusion arrived at from a study
cave-deposits is that some progress towards civilisation
k place in Palæolithic times. It has been observed that
caves which contain a succession of accumulations, the
er beds of the series are frequently charged with human
plements which exhibit better finish and more varied
ign than those that occur in the lower and older beds.
nt's Cave supplies us with a good example, and many
ilar cases might be cited. It is the conviction, indeed,
not a few archæologists, especially in France, that there
e several distinct stages of culture or advance in the
æolithic period—each marked by the special character of
implements fashioned by Man. Sometimes only one of
se stages is represented in caves; in other cases two or
re stages may be present. M. de Mortillet recognises four
ges, which, beginning with the oldest, are the Chellean,
Mousterian, the Solutrian, and the Magdalenian epochs.
e Chellean epoch is sparingly represented in caves, but, as
shall see by-and-by, is abundantly displayed elsewhere.
this epoch belong the more coarsely-made implements,
ny of them consisting of flint nodules, more or less rudely
pped into the required shape. From their form it is sup-
sed that they were not hafted but used in the hand. The
plements belonging to the later epochs are of much more
ied design, and show altogether better workmanship.
ith them are now and again associated objects fashioned
bone, teeth, horns, and antlers, some of which exhibit
figures of animals engraved or sculptured. Whether
s classification will ultimately be generally accepted is
certain. But the geological evidence has clearly shown
t the Chellean type of implement certainly preceded
Europe that which is known as the Mousterian; whether
e Solutrian and Magdalenian succeeded the Mousterian or

were in part contemporaneous with it, future investigations must be left to decide.

Yet another fact must be mentioned. In most of the caves which have yielded Palæolithic and Neolithic relics there is strong evidence of a break in the succession of deposits. The Neolithic layers are almost invariably sharply marked off from the older series. In Belgium, for example, the latter are separated from the former by a mass of yellow clay charged with large and small angular stones—a kind of 'rubble-drift,' in short. In other regions sheets of stalagmite or beds of earthy débris, or of silt and sand, may intervene between the Palæolithic and Neolithic accumulations. Moreover the mammalian faunas of the two epochs are widely different. No sooner do we leave the older deposits and pass up into the overlying Neolithic layers than we find ourselves in quite another world. The hyæna and lion, the mammoth and rhinoceros have taken their departure, and we are in presence of that group of animals which includes the common indigenous European forms of our own day. There is no gradation—no insensible passage from the latest Palæolithic into the oldest Neolithic stage. Something of the kind is said to have been observed in certain caves in the Pyrenees, but the evidence referred to is far from being conclusive, and cannot weigh against that which has been so abundantly furnished by the caves of North-western Europe.

If the cave-deposits of Pleistocene times suggest a high antiquity for our race, the evidence supplied by the contemporaneous river-accumulations points more emphatically still in the same direction. In our own country these deposits are typically represented by the gravels, &c., of the Thames Valley, where they have long been studied by geologists. The general coarseness of the gravels, and the broad area over which they are distributed, have led to the conclusion that, as Mr. Whitaker remarks, 'the old river must have been larger and of a more torrential character than the present one.'[1] The 'river-drifts,' as they are called, clothe the slopes of the valley in irregular sheets, which occasion-

[1] 'Geology of London,' *Mem. Geol. Survey of England and Wales*, 1889. p. 386.

lly assume the form of terraces—rising one above the other. ccording to Mr. Prestwich and others, these terraces have een formed during the gradual excavation of the valley—eriods of erosion having alternated with periods of accumula-ion. In this view the highest terraces on the valley-slopes re the oldest—the lower terraces having been deposited uccessively as the valley was deepened and narrowed by he action of the river. Unfortunately the terraced aspect eferred to is not so conspicuous or well-marked a feature of hose 'drifts' as it is of the fluvio-glacial gravels of the lpine Lands. One terrace shades off into another, and fre-uently we see nothing save a more or less continuous sheet f gravel and loam mantling the slopes of the valley. In any cases, therefore, it is hard to say whether the beds at he higher levels are younger or older than, or of the same ge as the 'drifts' lower down. Hitherto geologists have ot succeeded in tracing any general succession in the leistocene deposits of the Thames. The only attempt at lassification consists in a rough separation of the 'drifts' nto a high-level and a low-level series, between which it is onfessedly impossible to draw any definite line of demarca-ion. In accordance with the views of Professor Prestwich, he high-level deposits are considered to be the older of the wo series. There are certain facts, however, which lead ne to doubt whether this classification is altogether reliable. To one can study the remarkable account of the Pleistocene drifts' of Northern France given by M. Ladrière without eeling convinced that English geologists have not yet ucceeded in completely unravelling the structure of the orresponding 'drifts' of the Thames. As M. Ladrière's bservations[1] throw much light on the whole question f the origin of the deposits in question, it will be well to onsider his conclusions before we treat further of the leistocene river-drifts of our own country.

M. Ladrière's investigations commenced in 1875, and have ince been carried on with great assiduity. He has now tudied in detail the Pleistocene 'drifts' throughout the orth of France and the contiguous parts of Belgium, and

[1] *Annales de la Soc. géol. du Nord*, t. xviii. p. 93; t. xix. p. 339; t. xx. p. 22.

has surveyed the regions watered by the Sambre, the Escaut (or Scheldt), the Somme, &c., together with the valley of the Seine. His conclusions are thus based upon a broad foundation of personal observation, and on that account are all the more deserving of our attention. It is always a very great advantage to have a wide area examined in detail by one competent geologist, because he is able to show what are the main or chief features, and what part of the evidence is of subordinate importance. M. Ladrière does not discuss any theoretical considerations—his object has been simply to ascertain beyond doubt what is the true succession of the Pleistocene deposits. And he believes he has established certain general conclusions—which may be briefly summarised. The Pleistocene of the North of France, according to him, represents three great periods of formation. Each of these, he says, is marked by a series of deposits which constitute a definite geological stage. These are, from below upwards, (*a*) gravel or 'diluvium,' (*b*) sand, (*c*) loam or clay, and peat or peaty loam—a kind of vegetable earth that indicates an arrest of sedimentation. The three stages composed of these several accumulations differ in character, and are separated the one from the other by an unconformity or discordance in the stratification. In some places, as in the north-east part of the plateau of the Escaut, the three series occur in regular succession. In other places, as in Artois and Picardy, the deposits are less important and very irregular—the three stages being rarely seen together in one and the same section. The river-drifts in the neighbourhood of Paris are analogous to those of the plateau of the Escaut, while in the region between the Sambre and the Oise, where the two lower stages are well developed, the upper stage is only sparingly displayed.

The three stages are constituted as follows, the beds of each stage being given in ascending order :—

LOWER STAGE.

Diluvium, or Lower Gravel.—In the Paris Basin these gravels consist of well water-rolled materials, and in the northern parts of France of roughly rounded stones, gravel becoming less and less water-worn as it is followed up the sides of the valleys. The deposit is most strongly developed in the valleys of the Seine, the Somme, and the Oise. Amongst its mammalian remains are those of mammoth, woolly rhinoceros ; and in addition to these in the valley of

he Seine we have *Elephas antiquus*, *Rhinoceros Merckii*, &c., occurring in the asement accumulations of gravel.

Coarse Sand, with occasional layers of flints.

Clay, with vegetable débris and shells (*Helix*, *Succinea*, &c.). In some egions this passes into a sandy clay; in others it is less arenaceous, and conains chalky matter.

Peat, sometimes pure, but more usually a peaty loam, with shells (*Lymnæa*, *Succinea*, *Helix*, &c.).

This 'peat' forms the highest bed of the 'lower stage,' all the members of which are characterised by their greyish colour. They constitute M. d'Archiac's alluvion ancienne,' M. Belgrand's 'gravier de fond' and 'alluvions,' and the diluvium gris' of MM. Hébert and De Mercey. Flint implements of the Chellean type occur throughout.

Middle Stage.

The 'lower stage,' which is so well conserved in the region of the Escaut and the Sambre, has been subjected to considerable erosion in the Paris basin. This is well seen in the valley of the Somme, especially in the neighbourhood of Abbeville. At that place the deposits of the 'middle stage' occupy hollows of erosion in the 'lower stage,' fragments of the latter being enclosed in the overlying accumulations. The 'middle stage' is constituted as follows:—

Middle Gravel.—This bed is never thick; it is composed of a reddish argillaceous or gravelly sand, crowded with angular stones, mostly flints, and in some places with large flint nodules, evidently derived from the Cretaceous rocks of the neighbourhood. Now and again it contains the débris of the subjacent 'lower stage,' such as wood, peat, shells, bones, worked flints, &c. The bed is well developed in the neighbourhood of Paris and in the Somme, but occurs more sparingly in the north, where it is eventually represented by a single layer of flint, or even disappears entirely. In this case, the demarcation between the lower and the middle stage is simply indicated by a line of erosion.

Reddish sandy Loam.—This bed is occasionally represented by a coarse sand with angular flints. It is commonly present in the neighbourhood of Paris and the valley of the Somme, but is only sparingly represented in the north, where it is often wanting.

Variegated Loam.—Somewhat arenaceous, of a greyish colour, containing vegetable débris and some shells (*Succinea*). Towards the bottom yellow and grey layers alternate. The bed is particularly distinguished by its colour, and by the presence of numerous filiform ferruginous concretions. This clay is widely distributed in the valleys of Northern France, but in some places it is wanting.

Loam with black Stainings.—This is a very fine smooth deposit with black carbonaceous markings, and is more constant in its occurrence than the *variegated loam* and the *reddish sandy loam.* When these two are wanting it rests directly on the *middle gravel.* It is met with throughout all Northern France.

Fissile Loam (of a brownish red colour).—Its colour and structure are very characteristic. M. Ladrière says it occurs throughout all the regions he has surveyed.

Ash-grey or white Loam.—A thin, sometimes peaty, bed which has yielded shells (*Succinea*, &c.). It forms the highest member of the 'middle stage,' and is almost constantly present throughout the basin of the Escaut, appearing likewise in the valley of the Seine, and proving clearly, from its position, that the 'middle stage' forms as distinct a group as the 'lower.'

The 'middle stage' does not rise to the tops of the higher hills, nor does it descend quite to the borders of the existing valley, but it nevertheless has a considerable extension. According to M. Ladrière, the 'diluvium rouge' of other geologists corresponds in whole or in part to his 'middle stage.' Flint implements of the Chellean type occur, but these have probably been derived from the deposits of the 'lower stage.'

UPPER STAGE.

The upper stage comprises three beds, as follows:—

Upper Gravel.—This is a thin deposit composed of little angular fragments of flint, together with other stones, embedded in a coarse sand. It contains shell-fragments, &c., derived from the underlying beds. This bed is remarkably regular in the Paris Basin, where, without ever attaining a great thickness, it yet here and there occurs in masses which occupy hollows of erosion in the subjacent deposit. It is more rarely present in the northern part of France, but even when entirely absent the separation between the two stages is not the less well-marked by a line of erosion.

Ochraceous Loam or Löss ('Ergeron').—This would seem to be the most important of all the old 'river-drifts.' It is met with at very different levels, appearing to attain its greatest development upon the southern flanks of valleys and terraces, especially at the places where valleys become confluent. Its composition is apparently influenced to some extent by the character of the underlying rocks. Thus, where the 'subsoil' is argillaceous and sandy, it is very fine and smooth, of a clear yellow colour, and contains snail-shells. In such regions it shows no trace of calcareous matter. Its bedded character is indicated by the presence of numerous alternate layers and lines of sand and clay. In other places, as in Cretaceous districts, it becomes calcareous. In the Paris basin, for example, shells, chalk granules, and flint débris form more or less regular beds in the deposit, calcareous concretions are common, while carbonate of lime disseminated through the mass gives it a pale greyish colour.

Upper Clay or Brick-earth.—The preceding deposit is generally overlaid by this *upper clay*, but there is not the least trace of erosion between the two. The brick-earth is readily distinguished from the underlying löss by its brownish-red colour, its much more argillaceous character, by the complete absence of organic remains, and by an entire want of bedded arrangement.

In general terms it may be said that the 'upper stage' extends from the highest levels down to the bottom of the valleys. It rests discordantly sometimes upon the 'middle stage,' sometimes upon the 'lower,' or upon another geological formation altogether. Judging by their disposition, their extension, and their structure, the three beds constituting the 'upper stage' appear to have been formed successively, without any interruption, under the influence of some general phenomena. Flint implements of the Mousterian type have been found in the 'upper gravel' or at the base of the 'ochraceous clay.'

In concluding his paper, M. Ladrière remarks that the three stages can be followed from the bottoms of the valleys up to the plateaux, where, however, they do not reach the greatest heights. They are obviously, he considers, the products of general phenomena. The frequent absence of some of the beds he attributes to erosion and denudation which supervened during the intervals that separated the several periods of accumulation. Each of the three stages is an independent formation—that is to say, no portion of one stage has been accumulated at the same time as any portion of another stage. Thus in the valleys of Northern France we have a triple series of Pleistocene deposits, separated the one from the other by a distinct break in the succession.

M. Ladrière has confined himself for the most part to the

ortant labour of establishing the stratigraphical order he 'drifts,' and has modestly refrained from discussing retical questions. There are certain obvious conclusions, 'ever, to be drawn from his observations. Thus we learn ; before the formation of the 'lower stage' the valleys already been hollowed out to a very considerable extent. n the bottoms and sides of the primitive valleys the sits of the 'lower stage' were laid down. Then followed riod of much erosion, during which the valley-accumula-s suffered extensive denudation. Next we have a return onditions which obtained when the 'lower stage' was g formed, and as a result, the deposits of the 'middle e' came into existence. To this period of accumulation cond epoch of erosion succeeded, which in its turn was wed by a third period of accumulation. It is not quite , therefore, that the valley-drifts have been deposited at essively lower levels during the gradual excavation of the eys. In point of fact, the deposits of the 'lower stage' in many places overlapped upwards by the accumulations he 'middle stage,' while the loams, &c., of the 'upper e' extend from the bottoms of the valleys up to the est levels attained by any of the 'drifts.' In short, the sits at the highest levels are amongst the latest of the stocene series.

When we come to examine the evidence a little more in il, we find that the Pleistocene 'gravels' may be roughly rated into two groups. One of these includes the great of the gravel-beds, which occupy the bottoms and sides e valleys up to a height of 80 or 100 ft. above the present rs. Of the fluviatile origin of these beds there can be no bt. They consist for the most part of well water-worn erials arranged in layers, which indicate the action of a r-current. The stones have all been derived from the nage-basins in which they occur; in a word, the beds uestion, as Prestwich and others have shown, are simply river-gravels. While these low-level gravels consist rally of well water-worn materials, this is not by any ns invariably the case. Sometimes the stones are angular subangular, and the whole aspect of the deposit be-ns tumultuous action. Now and again, too, the beds

contain large erratics, which could only have been carried by river-ice; and here and there the bedding is disturbed, as if from the running aground of ice-rafts. The bulk of the low-level gravels, therefore, must be assigned to river-action. Such unquestionably is the origin of the so-called 'diluvium' or gravel of the 'lower stage.' The 'gravels' of the 'middle' and 'upper stages' offer a strong contrast to the 'diluvium.' While the latter often attains a great thickness, the former are always thin, and not infrequently are represented by a mere line of stones. Moreover, they are entirely of local origin, and consist of angular flints, &c., together with débris derived from immediately adjacent and subjacent accumulations. In a word, they have no character in common with true fluviatile gravels. They are made up of materials, as M. Boule has pointed out,[1] which have come down from the neighbouring plateaux and hill-slopes, and ought not to be termed 'gravels' —a word usually applied to deposits which have been formed and accumulated by water, as by brooks and rivers and the sea. With such deposits the so-called 'gravels' of the 'middle' and 'upper' stages have nothing in common, and the loamy accumulations which accompany these are in like case. They show stratification, often clearly marked out by lines and thin layers of angular stones, but this stratification differs entirely from that of a fluviatile accumulation. The latter is always more or less parallel to the inclination of the valley-bottom, while the loamy beds dip at a high angle down the sides of the valleys, which they cover like a cloak, while they are never arranged in the form of terraces. Their leading features have been very concisely summed up by M. Boule. Not only do the loams show this steep inclination, but they contain throughout the débris of land-plants and land-shells. All the appearances, according to him, betray the action of pluvial waters which have re-arranged, carried away, and distributed over the flanks of the hills and sides of the valleys the loams and other residual products which have resulted from the long-continued weathering of Cretaceous and Tertiary rocks. Whether or not we accept this interpretation of the evidence, the fact remains that the loams are essentially local in origin: their character is everywhere

[1] *L'Anthropologie*, 1892, p. 428.

luenced by the petrographical nature of the adjacent and derlying rock-masses.

In the valleys of Northern France, therefore, we have dence of three successive epochs, each of which presented ; same phenomena, in the like order. First, we have the ers flowing down their valleys and distributing the gravels the lower levels. Towards the close of this period loams re spread from the plateaux down the contiguous valley-pes. Then ensued a more or less prolonged period when ms ceased to accumulate to the same extent. The surface-ters now dug into the deposits, which were thus trenched, rowed, or even in great part denuded away. The 'middle ge' exhibits the same succession of events. The low-level vels in the bottoms of the valleys must belong in part to s stage—for the rivers doubtless flowed without interrup-n during the whole of the Pleistocene Period. For obvious sons, however, it will not always be possible to separate ; low-level gravels into successive stages, since rivers tend denude and re-distribute their accumulations, and thus ds of widely different age may often occur side by side in h a way as to suggest their contemporaneous origin. But, we shall learn later on, the testimony of the mammalian nains of the old river-gravels leads to the belief that these re laid down at different periods and under varying climatic nditions. The coarse 'angular gravels' and the loams of e 'middle stage' show that after the 'drifts' of the older ge had been much denuded, vigorous superficial action ain came into play, and much débris travelled down the pes of the land into the valleys and other hollows. Next, before, erosion and denudation succeeded accumulation, d the older 'drifts' suffered extensive waste. Then ensued e period represented by the deposits of the upper stage. ce more immense quantities of superficial materials were rried down from the heights and made their way into the lleys. It is worth noting that the accumulation of these ter loams was marked by curious disturbance of bedding. us in some places the younger and older valley-drifts are gether bent, folded, and puckered—appearances which re-ll the 'trail' and 'underplight' described in Chapter XXVII.

Let us now return to the old valley-drifts of the Thames.

In all essential characters these agree with the similar accumulations in the valleys of Northern France. Like them, they have yielded flint implements and remains of extinct and exotic mammals. The English gravels, like those of the Seine, &c., attain their greatest thickness also at low levels, and in such positions they are made up largely of well-bedded and distinctly water-worn materials. At the higher levels the 'gravels' consist chiefly of angular fragments, and show no conspicuous traces of river-action. And the same is the case with the loams and brick-earths which cloak the sides of the valleys and sweep upwards to the plateaux. Professor Prestwich's classical papers on the Pleistocene river-drifts of France and Southern England have led geologists to believe that the gravels and loams are merely terms of one and the same series. The gravels at the higher levels are supposed to have been deposited by the rivers when they were beginning to excavate their valleys—the loams at still higher levels being the flood-accumulations of the same rivers. As the river deepened their beds they left successive terraces of gravel and sheets of flood-loams upon the slopes of the valleys, at constantly diminishing elevations. The high-level deposits, if such be their origin, must therefore be the older terms of the series. From the precise and extensive observations of M. Ladrière, however, one is led to suspect that the division of the valley-drifts of the Thames, &c., into an older high-level and a younger low-level series is not as well founded as has hitherto been believed. When we find that all the three stages of the French geologist cloak the lower slopes of the Seine Valley, while only the upper or youngest stage is represented at the highest levels; and when we learn that these appearances are repeated again and again throughout the valleys of Northern France and the contiguous regions of Belgium, we begin to doubt whether the classification adopted by geologists for the 'drifts' of the Thames Valley can be sustained. If the valleys of Northern France had been deeply eroded before the formation of the lower and oldest drifts, it is improbable that the excavation of the valleys of Southern England had not made equal progress before the formation of our Pleistocene gravels and loams. That very considerable erosion was effected during

Pleistocene times goes without saying, but the amount of that erosion would seem to have been exaggerated. At all events, it is only the bedded gravels at the lower levels which are certainly of fluviatile origin. The high-level loams and angular gravels of the Thames Valley, which extend upwards to the plateaux, are probably local formations like the similar accumulations in Northern France. Hitherto, however, no such triple series as that described by M. Ladrière has been observed in Southern England. But we may note that in England, as in France, the better-formed flint implements occur in or underneath the younger loams, while the more archaic types are met with in the older subjacent gravels. The interesting discoveries made of recent years by Mr. Spurrell, Mr. Worthington G. Smith, Mr. J. Allan Brown, and others lead, indeed, to the conclusion that the high-level drifts of the Thames Valley are upon the whole younger than the old fluviatile gravels which are restricted to the bottom and the lower slopes of the valley. These younger loams and brick-earths seem to extend from the bottom of the valley up to the highest levels, and thus to overlap the older accumulations.

At Crayford, near the mouth of the Thames, Mr. Spurrell discovered in deposits of brick-earth and sand (at a height of 70 ft. above the sea, and a depth of 36 ft. from the present surface) what appears to have been a Palæolithic workshop. This was represented by a dense layer of flint chips, which had evidently never been disturbed since the materials were operated upon, for Mr. Spurrell was able to piece many of the flakes, and to demonstrate that the object sought was the manufacture of haches. He even succeeded in replacing a set of flakes in their relative positions around a hache, so as to form a restoration of the original block of flint used by the old workman. Nay, the very spot on which the tool-maker sat was suggested by 'the disposition of a heap of flakes which lay divided by two slight lines and other signs,' Mr. Spurrell inferring that the operator squatted on the sand with his legs but slightly apart.[1] 'Some of the smaller chips leave no doubt that, besides the coarser operations of blocking-out, very fine work indeed was attempted.' Mam-

[1] *Quart. Journ. Geol. Soc.* vol. xxxvi. p. 544.

malian bones were found associated with the flints, amongst them being part of the lower jaw of a young specimen of woolly rhinoceros. Splintered bones occurred in such numbers as to suggest that they had been broken for food. The brick-earth at Crayford is banked against an old cliff of chalk, and shows a disturbed surface underneath gravel. This latter, according to Mr. Spurrell, came down in the form of rushes from a high-level sheet of gravel which caps the chalk. The materials descended with some force, crushing into the softer brick-earth and sand, and making festoons and loops when seen in section. In short, we have here the phenomena already described as characteristic of 'trail.'

At Stoke Newington Common, at 90 ft. or so above the sea, Mr. W. G. Smith discovered what he has termed a 'Palæolithic Floor,' buried underneath four or five feet of sandy loam, and resting upon the surface of old river-gravels.[1] The 'floor' consists of a few inches of subangular gravel, and is crowded with unabraded tools, weapons, flakes, &c., obviously occupying the position in which they were left by the Palæolithic workmen. This remarkable 'floor' has been traced by Mr. Smith in many surrounding places, leading him to believe that it formerly 'extended over the whole of East Middlesex, into Herts as far as Hertford and Ware, and on both sides of the Thames from London to the Nore.' At one place (north of Stoke Newington Common) the floor occurs in duplicate—a thin layer of sand separating the two land-surfaces. From this it is obvious that the 'floor' was liable now and again to be flooded. After the lower 'floor' had been thus covered 'with a thin coating of sand, the men then walked over the newly-deposited sand, and made other tools on the new floor.' Most of the implements met with on the 'floor' are small, few of them being suitable for weapons. Nearly all, Mr. Smith remarks, are obviously tools. The tool-makers appear to have been a gregarious folk, 'living in close company, in enormous numbers,' over a wide tract of country. From the abundance of 'scrapers' amongst the implements, and from the occurrence of drilled fossil shells, it is inferred that the folk scraped skins for clothing, and probably wore beads for ornaments.

[1] *Journ. Anthrop. Inst.* vol. xiii. (1884).

The 'floor' does not always rest directly on the gravels, some places a few feet of sand intervening. In the underig gravels, which are obviously older than the 'floor'-beds, other series of implements is met with. These, according Mr. Worthington G. Smith, have all the marks of much ater antiquity. This is shown 'not only by the condition the flint of which they are made, but by the nature and ke of the implements themselves.' They are, as a rule, siderably larger than the tools of the 'floor,' and the very and neat secondary chipping which the latter exhibit is known in the case of the former. Amongst them, howr, scrapers occur, showing that the old workmen knew v to dress skins. Still lower down in the gravel-beds, at base of the 20-ft., and even 30-ft. excavations, often ongst blocks of sandstone a foot and a half across, and ighing from two to five hundredweight, and where all stones are deeply ochreous, a third class of implement urs. These implements are likewise ochraceous, greatly aded, and extremely rude. No distinct knife and scraper ms occur amongst them—the implements being suitable ly for hacking and battering. It is probable, therefore, it the old savages at this early stage did not dress skins.

According to Mr. W. G. Smith, it has now been proved yond dispute that the whole of the 'Palæolithic floor' scribed above is covered with 'warp and trail,' except in ces where the surface has been artificially disturbed in dern times. The 'contorted drift,' as he terms the orphous materials that overlie the brick-earth, &c., in ich the 'floor' occurs, has in several places disturbed the or, ploughed it up, and sometimes pushed underneath it. he undulation and contortion of the upper drift material,' continues, 'seem to show that it was laid down by moving or frozen mud from the north. The abraded and whitened plements and flakes, sometimes embedded at all angles in upper contorted drift, were, no doubt, caught up from exposed land-surfaces, and carried southwards by slowlyving half-frozen mud.' No relics of Palæolithic age cur above these contorted deposits.[1] Amongst the implents in the 'contorted drift' are certain archæic forms, of

[1] *Man, the Primeval Savage*, 1894, p. 207.

the same character as those that occur towards the bottom of the valley-gravels. They are of course derivative, as Mr. Smith has shown, from an older land-surface, and must in many cases have come from heights which are no longer in existence. We have here, in short, the same appearances that characterise the valley-drifts of Northern France.[1]

Mr. J. Allan Brown has likewise traced three or four more or less distinct lines of former land-surfaces in the 'drifts' of the Ealing district.[2] One of these occurs at a level of from four to six feet below the surface, a second at from seven to eight, and a third at from ten to fourteen feet. At Acton (100 ft. above the sea), underneath loam and brick-earth, at a depth of six feet from the surface an old 'floor' was exposed from which 400 implements, flakes, and fragments were obtained. At the second level (eight feet from surface) a layer of bleached stones and humus was disclosed, and yielded five or six specimens. From the lowest level (ten to eleven feet) only three specimens were got. The sharply angular, unabraded aspect of the implements on the upper 'floor,' and their occurrence together in nests, led Mr. Brown to believe that they were manufactured in place. Coarse gravel with seams of sand underlaid the brick-earth and loam. I need only add that the deposits described by Mr. Brown are overlaid by 'trail.'

I regret that considerations of space forbid entering into further detail, and I must content myself, therefore, by some

[1] Mr. B. Harrison has discovered a number of extremely primitive implements at high levels on the chalk plateau of Kent. They are found scattered over the surface, but in one or two cases they seem to have been met with in the 'red clay-drift' which caps the plateau. Professor Prestwich is of opinion that these implements really appertain to this high-level clay-drift, and if so this would indicate a very great antiquity for them. They would necessarily date back to a period before the valleys containing the implementiferous deposits described above had come into existence. They might, therefore, well be of pre-glacial age. It is no reply to Professor Prestwich's argument to say that implements equally archaic in character have now and again been obtained in the valley-drifts. On the other hand, not a few of the less rude implements discovered by Mr. Harrison are of the same types (Chellean) as those occurring in the oldest valley-gravels. If it should eventually be proved that the plateau-implements are really of the same age as the plateau-drifts, the 'human period' will go back to a much earlier date than has hitherto been dreamed of; for the 'drift' referred to has travelled from the south at a time when the Central Wealden area formed a low mountain-range, which Professor Prestwich thinks might have been 2,000 to 3,000 ft. in height. (See *Quart. Journ. Geol. Soc.* 1889, p. 270; 1891, p. 126; *Journ. Anthrop. Inst.* 1892, p. 246.)

[2] *Quart. Journ. Geol. Soc.* vol. xlii. p. 192; *Trans. Middlesex Nat. Hist. Soc.* 1889.

neral remarks on the prominent characters of the valley-fts of Southern England. It has been shown by Professor estwich and others that the 'drifts' that occur at the ghest levels above the present streams possess certain broad aracters that serve to distinguish them roughly from the rifts' that occupy the lower levels of the valleys. As a le the former are the coarser, and frequently show little or trace of arrangement by ordinary river-action. The low-vel deposits, on the other hand, are usually finer grained d more or less distinctly bedded, as if spread out by the tion of streams and rivers. In these respects, then, the nglish valley-drifts correspond to the similar accumulations the valleys of Northern France. It must be noted, more-er, that the latest formation in the English valleys is that own under the name of 'trail,' which characterises low-vel and high-level deposits alike, and the same would appear be the case in some of the valleys in Belgium and Northern ance.

According to Professor Prestwich,[1] the shells met with in e high-level beds have a northerly range, and the absence southern species tends still more to distinguish these beds om those of lower levels. In the latter there occur in great undance two species of shells (*Corbicula fluminalis* and *Unio toralis*), neither of which is now found living in England, it tenanting the rivers of more southerly latitudes,[2] a fact at seemingly corroborates the inference deduced from the pearance of the beds themselves.

Again, it cannot be denied that northern types of mam-alia are most characteristic of the high-level gravels, and uthern forms of those at the lower levels. And notwith-anding that remains of both northern and southern species e not uncommonly commingled, still it is a fact, although, Sir J. Lubbock remarks,[3] 'too much importance must ot be attached to the observation, that our ancient hippo-otamus has been less frequently found in association with e mammoth and the hairy rhinoceros, than with *Elephas*

[1] *Philosophical Transactions*, 1864, p. 279.

[2] *Corbicula fluminalis* is now extinct in Europe, but it still inhabits the le and abounds in Cashmere; *Unio littoralis* lives in the Seine and the ire.

[3] *Prehistoric Times*, third edition, p. 299.

antiquus and *Rhinoceros hemitœchus* (Falc.),' two species which had a more southerly range.

The fact that the remains of northern and southern forms are commingled in Pleistocene river-deposits is only what one might have expected. Those who study the formation of fluviatile sediments will readily understand how fossils, entombed at widely separate intervals, may come to occupy the same level. Rivers are constantly cutting down through their own deposits, and again filling up the excavations they make. In this way gravel and sand are banked against similar beds, which may belong to a much greater antiquity; and the line of junction it is often impossible to determine, the one deposit seeming to shade into the other. And thus beds which appear to be continuous and of contemporaneous origin may, and in point of fact do, frequently deceive us in these respects.

There is nothing, therefore, abnormal or extraordinary in the intermingling in our Palæolithic beds of mammalian remains belonging to widely separated life-provinces. It would have been surprising, indeed, had it been otherwise.[1]

In the former editions of this work I devoted a chapter to the discussion of the climate which obtained in Palæolithic times—basing my remarks chiefly on the character of the mammalian faunas with which primeval man was associated. The general conclusion to which I came was that the occurrence of northern, temperate, and southern forms in our cave-accumulations and valley-drifts pointed rather to secular than to seasonal migrations. In opposition to those who believed that the Palæolithic epoch was marked by strongly contrasted summers and winters, inducing great annual migrations, I maintained that the evidence betokened an alternation of cold and genial climatic conditions. The same view was subsequently set forth in my 'Prehistoric Europe,' where I have brought together the evidence derived not only from the mammalia, but from the former distribu-

[1] The implementiferous valley-drifts of the Thames have yielded the following forms: wolf, fox, lion, wild cat, hyæna, otter, brown bear, grisly bear, bison, urus, musk-sheep, roe, red deer, Irish deer, reindeer, elephant (*Elephas antiquus*), mammoth, horse, hippopotamus, woolly rhinoceros (*Rhinoceros antiquitatis*), *R. leptorhinus*, *R. megarhinus*, wild boar, water-vole, pouched marmot, beaver, &c.

n of molluscs and plants. The facts which have since ne to light all point clearly to the same conclusion—namely, ıt during Palæolithic times great changes of climate took ce. All the Pleistocene formations which occur outside the glaciated areas—the valley-drifts, lignites and peat, ustrine deposits, and calcareous tufas—tell the same tale changing climatic conditions. During one stage of the eistocene period 'clement winters and cool summers pertted the wide diffusion and intimate association of plants ich have now a very different range. Temperate and ıthern species, like the ash, the poplar, the sycamore, the -tree, the Judas-tree, &c., overspread all the low-grounds France as far north at least as Paris. It was under such nditions that elephants, rhinoceroses, hippopotamuses, and st herds of temperate cervine and bovine species ranged er Europe, from the shores of the Mediterranean up to the itude of Yorkshire, and probably even further north still, d from the borders of Asia to the Western Ocean. Despite e presence of numerous fierce carnivora—lions, hyænas, gers, and others—Europe at that time, with its shady rests, its laurel-margined streams, its broad and deepowing rivers, a country in every way suited to the needs of race of hunters and fishers—must have been no unpleasant abitation for Palæolithic man.' But during another stage f the Pleistocene period, the climate of our continent presented the strongest contrast to those genial conditions. At ıat time 'the dwarf birch of the Scottish Highlands, and ıe Arctic willow, with their northern congeners, grew upon ıe low-grounds of middle Europe. Arctic animals, such as ıe musk-sheep and the reindeer, lived then, all the year ound, in the south of France; the mammoth ranged into pain and Italy; the glutton descended to the shores of the editerranean; the marmot came down to the low-grounds the foot of the Apennines; and the lagomys inhabited the w-lying maritime districts of Corsica and Sardinia. The nd- and fresh-water molluscs of many Pleistocene deposits ll a similar tale: high alpine, boreal, and hyperborean rms are characteristic of those deposits in central Europe; ven in the southern regions of our continent the shells testify a former colder and wetter climate. It was during the

climax of these conditions that the caves of Aquitaine were occupied by those artistic men who appear to have delighted in carving and engraving.'[1] Such, in brief, is the testimony of the Pleistocene flora and fauna of extraglacial regions.

Before considering the evidence supplied by the Pleistocene deposits in the extraglacial tracts of central Europe, it may be well to indicate shortly what relation our cave-accumulations and valley-drifts bear to our glacial and fluvio-glacial deposits. Now, in the first place, it is obvious that the valley-gravels and cave-accumulations contain essentially the same kinds of mammalian remains—the northern and temperate and southern forms all belong to the Pleistocene period. In a word, the valley- and cave-deposits are approximately contemporaneous. Then, in the next place, it is not less obvious that the mammalian fauna of the interglacial beds is practically identical with that of the caves and valley-drifts. The presumption, therefore, is that our cave-accumulations and valley-drifts are the equivalents in time of our glacial and interglacial deposits. We have seen that in Victoria Cave the remains of southern and temperate species are overlaid by glacial deposits, and the like is the case with the northern and temperate forms met with in the caves of the Vale of Clwyd, where also Palæolithic implements occur. Again, the Pleistocene mammalia have left their remains in the interglacial beds of Kelsea, which rest upon and are covered by boulder-clay, and the same is the case in the interglacial beds of Scotland. In the south of England no true glacial deposits occur, but these, as we have seen, are represented by rubble-drift and 'trail.' Now on the coast of Sussex Pleistocene deposits with a temperate flora and fauna (including such forms as *Elephas antiquus* and *Rhinoceros leptorhinus*) are of later date than the ice-floated erratics of Pagham, and are overlaid by chalk-rubble, thus clearly occupying an interglacial position. Further, in the valley of the Thames the 'drifts' with Palæolithic implements and Pleistocene mammalian remains are everywhere overlaid by 'trail,' but are certainly younger in the main than the great chalky boulder-clay, and must therefore likewise be assigned to interglacial times. Lastly, as the valley of the

[1] *Prehistoric Europe*, p. 67.

hames appears to have existed before the formation of the ıalky boulder-clay, it is obvious that the Pleistocene 'drifts ' that valley must represent a long series of glacial and terglacial phases—the deposits having been continuously odified and remodified by the river during a protracted riod of time.

CHAPTER XXXVIII.

VALLEY-GRAVELS AND LÖSS OF CENTRAL EUROPE.

Alternating epochs of accumulation and erosion—Valley-drifts of the Rhine; sands of Mosbach, Darmstadt, and Hangenbieten; passage of valley-drifts into fluvio-glacial terraces—Rock-shelter of the Schweizersbild—Pleistocene of Thuringia—Löss, its composition, structure, distribution, and organic remains; successive tundra-, steppe-, and forest-faunas —Human remains in löss—Origin of löss; fluvio-glacial inundation-deposit largely modified and re-arranged by wind—Snow and dust-storms, and wholesale entombment of mammals—'Dreikanter'—Dead ice of arctic regions of Pleistocene age—Geological horizon of löss—Pleistocene deposits of extraglacial tracts contemporaneous with glacial and interglacial series.

IT is beyond my purpose to attempt a sketch of the evidence furnished by the Pleistocene river-gravels throughout Europe. In many parts of the Continent, indeed, the deposits in question are more or less imperfectly known; while of those that are well-known volumes might be written. But as my chief object is to ascertain the relation which such deposits bear to the recognised accumulations of the Glacial Period, I shall content myself with a short account of the Pleistocene drifts of certain tracts where they are typically displayed. Before treating of those regions, however, brief reference may be made to the facts already adduced from the valleys of Northern and Central France. Let it be remembered that in Northern France the valley-gravels, &c., bear witness to three periods of accumulation, separated the one from the other by epochs of erosion and denudation. On the bottoms of the valleys occur true river-gravels, while covering the valley-slopes and extending up to the plateaux angular gravels and loams of local origin are more or less strongly developed. These last would appear to have been formed in the same way as the similar drifts in the south of England. They point to the action of frost and thaw—the disintegrated subsoils, &c., slipping, creeping,

l flowing down the slopes towards the hollows and depres-ıs, where they became subject to the modifying action of ɜams and rivers. Such 'travelled subsoils,' therefore, we y look upon as the equivalents in time of the glacial ›osits elsewhere. The true river-gravels occupying the ley-bottoms are doubtless partly of glacial and of inter-cial age. The epochs of erosion which supervened after formation of each successive series of 'angular gravels l loam' are suggestive of interglacial conditions. While se obtained wholesale movements of the 'soil-cap' were ested and vegetation clothed the valley-slopes,—rills, oks, and streams cutting their way through the angular vels and loams of the preceding cold period. If this the true reading of the evidence, then, in Northern ınce we have evidence of three separate and distinct cold ›chs with two intervening epochs of milder or temperate ıditions. Again, in Central France as we have seen ıapter XXXIV.), certain river-terraces containing Palæo-ıic implements and mammalian remains are obviously interglacial age, since they can be shown to be of later e than the oldest morainic accumulations, while they are arly older than the youngest moraines of that region.

Turning our attention to the valley of the Rhine, we rn that the Pleistocene gravels and loams of that region ve also yielded relics of Palæolithic Man and the mammals th which he was contemporaneous. For our present pur-se the most instructive section of the great valley is the ›ad flat that extends between Bâle and Bingen. Here, if ywhere, it should be possible to trace the relation between ɜ old river-deposits and the accumulations of the Glacial riod, for the region is overlooked by the Jura, the Vosges, d the Black Forest, each of which formerly nourished ısiderable glaciers. We are not surprised, therefore, to d that the sand and gravel of the valley can be followed, the form of well-marked terraces, right into Switzerland, ıere they pass into the fluvio-glacial detritus of that ıntry. In like manner they can be traced continuously o the mountain-valleys of the Vosges and the Black rest, where they pass in the same way into true morainic avels.

At the foot of the Taunus, near where the Main mingles its waters with the Rhine, occur certain sand and gravel beds which are notable for their mammalian remains. They are best seen in the sand-pits which have been opened between Hofheim and Mosbach, at a height of about 450 ft. Amongst the species recognised in these deposits are *Elephas antiquus*, *Hippopotamus*, *Rhinoceros Merckii*, and many others, including lion, lynx, bear, badger, wild boar, elk, stag, roe-deer, antelope, bison, wild horse, beaver, &c. With these are associated many land- and fresh-water shells, some of which are still native, while others are no longer so, having retired to more westerly and southerly regions.[1] These sands constitute the first or '*Elephas-antiquus* stage' of the Middle Pleistocene, according to Dr. Kinkelin's classification. The second stage is characterised by the presence of *Elephas primigenius* and *Rhinoceros antiquitatis* (= *tichorhinus*), together with a number of land- and fresh-water shells. The beds are composed chiefly of coarse gravel, and are overlaid by loamy accumulations containing, in addition to the two pachyderms just named, horse, Irish deer, reindeer, hyæna, wolf, &c., and a number of land- and fresh-water shells, some of which are high-alpine and northern species. The Mosbach Sands are underlaid by very coarse gravels, charged with large rounded and angular blocks of sandstone. These gravels are unfossiliferous, and sweep up from underneath the overlying mammaliferous beds to heights of 600 to 900 ft. on the slopes of the Taunus. They undoubtedly betoken the action of tumultuous waters and floating ice, at a time when melting snows brought down much material from the hill-slopes into the valleys. These deposits form Dr. Kinkelin's Lower Pleistocene. The youngest 'diluvial' accumulations

[1] For descriptions of the Mosbach beds and their fauna see A. Braun, *Bericht d. Naturf.-Vers. in Mainz*, p. 142; F. Sandberger, *Die Land u. Süsswasserconchylien d. Vorwelt*, p. 758; O. Böttger, *Notizblatt des Ver. f. Erdkunde zu Darmstadt*, p. 321; C. Koch, *Erläuterungen z. geol. Specialkarte von Preussen*, &c., Blatt Wiesbaden, p. 41; F. Kinkelin, *Bericht über die Senckenberg. naturf. Ges. in Frankfürt a. M.*, 1889, p. 98; *Abhandlungen z. geol. Specialkarte von Preussen und den Thüringischen Staaten*, Bd. ix. p. 703; A. Andreæ, *Abhandl. z. geol. Specialkarte von Elsass-Lothringen*, Bd. iv. Heft 2; Schumacher, *Mitt. d. Commission für d. geol. Landes-Untersuch. v. Elsass-Lothringen*, Bd. ii. 1890, p. 184; H. Pohlig, *Die grossen Säugetiere der Diluvialzeit*, 1890. Further references to the literature of the subject are given by Dr. Kinkelin in his monograph in the *Abhandlungen* cited above, which contains the fullest description of the stratigraphical relations of the deposits.

e region are represented by a well-marked terrace, rising fifty feet above the surface of the river, and notable on unt of the numerous angular blocks and boulders which ntains. Some of these attain a large size: thus Kinkelin ions that two blocks (one of basalt, the other of gneiss) together weigh considerably more than two tons. He s that the transport of these numerous blocks bespeaks r and longer winters than are now experienced in the region. This terrace, according to the same geologist, e equivalent of the 'low-level terrace' of the Swiss gists, in other words it is on the same horizon as the inal moraines of the 'inner zone,' and is thus contemneous with the great glaciers of the third glacial period e Alpine Lands, the Black Forest, and the Vosges. The e gravels with erratics, which underlie the Mosbach s, he takes to be the equivalents of the moraines and)-glacial deposits of the second glacial epoch—that, ely, during which the Alpine glaciers had their greatest opment.[1]

'arther up the valley of the Rhine, between Hangenbieten Achenheim, not far from Strasburg, occur certain vial sands' which have yielded a rich molluscan fauna, could not have lived under cold climatic conditions, as must have obtained in that region during a glacial d. Professor Andreæ has shown that this fauna is not acial in character—it approximates to that of the)ach Sands, but does not contain quite so large a perige of extinct forms. It is also certainly not postglacial. beds overlying the shelly sands consist of various sands oams which, according to the same author, are indicative lder conditions. In a word, the diluvial sands of Hangeten are of interglacial age.[2]

Reference has already been made to the high- and lowfluviatile terraces of the Rhine, which, as Du Pasquier others have shown, are contemporaneous with the 'inner'

n the neighbourhood of Darmstadt a similar succession is met with. sand, rich in shells (both land and fresh-water) is underlaid and overlaid arse gravels, often cemented into conglomerate. The underlying conrate contains large angular blocks of sandstone. The sand is on the horizon as the similar accumulation at Mosbach. (G. Greim, *Neues f. Min., Geol. u. Pal.*, 1885, Bd. i. p. 142.)

Abhandl. z. geol. Specialkarte v. Elsass-Lothringen, Bd. iv. Heft 2.

and the 'outer' zones of moraines respectively. We have seen also that similar terraces, sweeping out from the valleys of the Vosges and the Black Forest, pass insensibly into the Rhenish fluvio-glacial flats. The Mosbach Sands, there can be no doubt, are older than the later of these terraces—they belong, in short, to the second interglacial period—that, namely, which succeeded the epoch of maximum glaciation. Advancing up the Rhine Valley into Switzerland, we reach Schaffhausen, in the neighbourhood of which some very interesting discoveries have recently been made by Professor Nuesch. About two miles north of the town, on the right bank of the river, is the Schweizersbild—a tree-girt meadow, in the midst of which rise three isolated stacks of limestone. At the foot of one of these, the face of which is somewhat overhanging, Professor Nuesch has discovered numerous remains of Palæolithic age. This, there can be no doubt, formed a rock-shelter during the so-called 'reindeer period.' The deposits met with in descending order are as follows[1]:—

1. Vegetable soil, &c., with fragments of limestone, 1½ ft. up to rather more than a yard.
2. Greyish earth, charged with many large and small fragments of limestone, 15 ins. to 2 ft. or more in thickness. It is sharply marked off from the overlying accumulation. On its upper surface, where it terminates against the rock, it shows a bed of cinders, 8 ins. to 11 ins. thick. The relics met with are all Neolithic, such as black and red potsherds, flint-flakes, fragment of a polished implement (serpentine), and numerous antlers (stag) fashioned into the form of picks, chisels, gouges, &c. The same stratum has yielded many human bones belonging to individuals of different age and sex; and also remains of brown bear, wolf, badger, hare, horse, ox (*Bos taurus*), urus (?) or bison (?), ibex, stag, roebuck, wild boar, domestic pig.[2]
3. Bed of small stones and angular fragments detached from the walls of the 'shelter,' mixed with very little earth. It increases in thickness from the interior to the exterior of the shelter, where it reaches a yard. This bed contains no worked objects. It is divided in two by a zone of earthy material, grey in colour and rich in the remains of rodents of the same species as those mentioned as occurring in bed 5. It shows a much eroded surface under the overlying bed 2.
4. Yellow or reddish earth, of variable thickness, but not exceeding 15 or 16 ins. Towards the exterior of the shelter it is darker, or even

[1] For the above short outline of Professor Nuesch's researches I am indebted to a paper by M. Boule (*Nouvelles Archives des Missions scientifiques et littéraires*, 1893), who had the advantage of examining the rock-shelter of Schweizersbild under the guidance of its discoverer. The animal remains have been described by Professor Nehring (*Verh. Berl. anthrop. Ges.* Bd. v.; *Potonié's Naturwissensch. Wochenschrift*, 1893, No. 10).

[2] Beside these remains of reindeer also occur; but as there is clear evidence of Neolithic sepultures, it is probable that the reindeer bones are *remaniés*—the Palæolithic layer having been dug into where the graves occur.

black, and has a baked or calcined aspect. We have here, in short, the site of an old hearth with the débris of Palæolithic feasts. Bones are very numerous, especially those of the reindeer. The species noted are brown bear, glutton, wolf, arctic fox, alpine hare, horse, ox or bison, ibex, reindeer, stag, ptarmigan and other birds, and fish remains. The Palæolithic relics include flint-flakes and implements of various forms, a bone harpoon, and divers other implements of bone, some of which show engraved designs and etchings representing reindeer and horse. Besides these are drilled shells and teeth, which have been used as ornaments. In a word, we have here relics of the men of the 'reindeer period.'

5. Yellow earth with small fragments of limestone. No traces of Man occur in this bed, but it is rich in the remains of small rodents. The species are:—pouched marmot, tailless hare, hamster rat (*Cricetus frumentarius*, *C. phæus*), field-mouse, voles (*Arvicola arvalis*, *A. agrestis*, *A. gregalis*, *A. amphibius*), torquated lemming, alpine hare, common mole (*Crocidura*, sp.), shrews (*Sorex alpinus*, *S. pygmæus*), ermine, weasel, arctic fox, reindeer, ptarmigan, and other birds and fish not determined. This bed has not been excavated completely, but is known to rest upon fluvio-glacial detritus.

M. Boule, who is so intimately acquainted with the læolithic deposits in the caves and rock-shelters of France, s no doubt whatever that the Palæolithic relics are of e same character and age as the similar relics found so undantly in France. At Schweizersbild the deposits arly overlie the morainic gravels of the third glacial och. And it is obvious that the men of the reindeer riod did not occupy the rock-shelter there until long after e glaciers had abandoned the low-grounds in the neighurhood of Schaffhausen. This is shown by the fact that tween the glacial gravels and the bed with Palæolithic ics there intervenes a mass of débris, evidently of subaërial gin, and containing not a trace of Man. In like manner the læolithic stage is separated from the Neolithic layer by a nilar sheet of subaërial origin—indicating that a long time psed after the departure of Palæolithic Man and before e advent of his Neolithic successor. There is, in short, a reak' between the two 'relic-beds.' What relation the posits of Schweizersbild bear to the moraines of the 'first stglacial stage' of glaciation (*i.e.* the fourth glacial epoch) s not yet been ascertained. The occurrence of a wellirked steppe-fauna in the lowest stratum (No. 5) is specially orthy of note, and will be referred to again in the sequel.

Leaving the valley of the Rhine we may now take a rapid ince at certain fluviatile deposits of Pleistocene age which cur in the neighbourhood of Weimar in Thuringia. The

well-known fluvio-lacustrine accumulations of that region are notable not only on account of their rich mammalian fauna, but for the occurrence in them of flint-implements. The beds consist of clays and arenaceous limestones—in the latter of which the organic remains chiefly occur. These beds appear to have been accumulated near the margin of a lake or, rather, the lake-like expansion of a river. They rest upon a great thickness of river-gravels, a number of the stones in which are of Scandinavian origin. In other words, the gravels obviously consist largely of materials which have been derived from the morainic accumulations of the great northern *mer de glace*, which at the climax of the Glacial Period reached the foot of the hills of Middle Germany. This lake must have existed for a considerable time, but eventually the river greatly deepened its bed, the lake was drained, and its accumulations were much denuded. Frequently the river rose in flood, and, overflowing the adjacent low-grounds, succeeded in covering the old lake-deposits with a thick sheet of loam. This erosion and flooding is believed to have taken place during another glacial epoch. Amongst the mammalian remains from the sandy limestone are those of *Elephas antiquus*, *Rhinoceros Merckii*, both rather plentiful; varieties of brown bear and bison, also not uncommon; a large horse and a beaver like those of the Mosbach Sands; red-deer or stag, most abundant of all. Less commonly met with are wild boar, lion, hyæna, panther, wolf, otter, roe-deer, and a large deer (*Cervus euryceros*). Besides these occur bones of water-birds and of pike, and land- and fresh-water shells. Amongst the latter *Belgrandia*, a form which is now restricted to Southern France, is very common. Of the land-shells several are no longer indigenous, but are met with farther east, as in the Carpathians, Caucasia, and Persia. Other forms represented are tortoise, cray-fish, and various insects. Numerous plant-remains likewise make their appearance, showing that the land was then clothed with a luxuriant vegetation—some of the trees belonging to species no longer growing wild in the neighbourhood of Weimar, or now extinct. Among the trees are oaks, ash, walnut, the American red chestnut, various willows, cornel, hazel, buckthorn, &c. The presence of charcoal and

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ly the larger grains being rounded. Frequently the accumulation shows a porous structure, and is penetrated by long, irregular, but approximately vertical, root-like tubes or canals, which are lined with carbonate of lime—a structure which imparts to the deposit a strong tendency to cleave or divide in vertical planes. Hence it usually forms more or less upright bluffs or cliffs, upon the margins of streams or rivers which intersect it. As a rule the mass shows little or no trace of bedding or arrangement in layers, except towards the bottom of the accumulation, where intercalated layers and even thick beds of sand make their appearance. Now and again, however, löss, which is otherwise typical, may exhibit lines of bedding throughout a considerable thickness. Very often it contains concretions or nodules of irregular and grotesque forms (*Lössmännchen*, *Lösspüppchen*, or *Lösskindeln*).

[1] A. Portis, *Palæontographica*, Bd. xxv. (1880) p. 141; Hans Pohlig, *Zeitschr. f. Naturwissenschaft in Halle*, 1885, p. 258; *Sitzungsber. d. niederrhein. Ges. in Bonn*, 1884, p. 47; *Die grossen Säugetiere der Diluvialzeit*, 1890, p. 51.

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ιerous flint implements and burnt bones shows that man contemporaneous with fauna and flora. Obviously the bach fauna is equivalent to that of the Mosbach Sands, is on the horizon of the '*Elephas-antiquus* stage' of the ɜr. The '*Elephas-primigenius* stage,' however, is likewise esented at Taubach by mammoth, reindeer, and pouched mot.[1]

Γhe Taubach-beds are overlaid by a thick mass of loam öss, which Dr. Pohlig believes to be the product of the r-floods of a glacial epoch. This raises the question of the in of löss—a question much discussed, and which, owing its important bearing upon the subject of Pleistocene ιate, must now be shortly considered.

Löss is certainly one of the most remarkable accumula- s of Pleistocene age. It may be described in general ns as a very fine-grained, yellowish, calcareous, sandy n, having little or no plasticity. Subjected to careful ng, it is found to consist largely of very minute grains ɿuartz with a slight admixture of argillaceous matter. ɜome districts the quartz-grains are more or less well- nded, while in other regions they are sharply angular— y the larger grains being rounded. Frequently the umulation shows a porous structure, and is penetrated long, irregular, but approximately vertical, root-like tubes canals, which are lined with carbonate of lime—a ιcture which imparts to the deposit a strong tendency cleave or divide in vertical planes. Hence it usually ns more or less upright bluffs or cliffs, upon the margins ɜtreams or rivers which intersect it. As a rule the mass ws little or no trace of bedding or arrangement in layers, ept towards the bottom of the accumulation, where inter- ιted layers and even thick beds of sand make their ap- ɾance. Now and again, however, löss, which is otherwise ical, may exhibit lines of bedding throughout a con- ɜrable thickness. Very often it contains concretions or lules of irregular and grotesque forms (*Lössmännchen*, *ɜspüppchen*, or *Lösskindeln*).

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The löss as thus described, is very widely distributed in Central Europe. We find it, for example, extending in a narrow belt along the southern margin of the great plain of Northern Germany, where it forms one of the most fertile tracts on the Continent. It is likewise well developed in the broad valleys of the Rhine and the Danube, and in the lower reaches of other wide valleys in Central and South-eastern Europe, as in those of the Theiss, the Drave, the Save, &c. It is in Southern and South-eastern Russia, however, where it attains its widest development, covering as it does a vast stretch of country, extending west and east between the valleys of the Pruth and the Volga. Its northern margin is approximately indicated by a line drawn between Lemberg and Kazan, by Kief and Tula—from which it sweeps south to the Black Sea and the Aralo-Caspian depression. Throughout this wide region it is usually very dark in colour, forming what is known as the *Tchernoziom*, or Black Earth.[1]

In the river-valleys of Central Europe the löss overspreads some of the old valley-gravels in broad sheets, and thus often assumes the character of a terrace or flat. It is by no means confined to the valley-bottoms, however, but sweeps up the slopes of the contiguous high-ground, sometimes to heights of 200 or 300 ft. or more above the existing rivers. Not infrequently, indeed, it even overspreads the plateau between adjacent valleys, wrapping the whole country, in short, like a mantle.[2]

In many regions this remarkable deposit is more or less abundantly charged with land-shells, while occasionally also fresh-water shells make their appearance. Frequently, however, shells of any kind are scarce, and now and again over a wide region they seem to be entirely wanting. Besides molluscs the remains of many of the Pleistocene mammals have been dug out of the same deposit, which has likewise yielded undoubted relics of Palæolithic Man. Amongst the organic remains are some that indicate an

[1] For an instructive résumé of our present knowledge of the origin and conditions of the soils of Russia see Prof. Dokuchaev's work, *The Russian Steppes: Study of the Soil in Russia, its Past and Present*, St. Petersburg, 1893.

[2] It is said to occur in the Carpathians at heights varying between 800 and 5,000 ft.

tic climate, while others strongly suggest steppe-condi-
ns, and yet others tell us of temperate forest-lands. It is possible that all those creatures could have lived side by e in the same region, and we are perforce led to conclude ıt the accumulation of the löss, whatever its origin may must represent a long period of time during which cli-ıtic changes took place. This conclusion, so reasonable itself, has been much strengthened by the discovery that, some places at least, the löss exhibits a succession of ınal zones—different suites of organic remains occurring different levels. For our information on this point we indebted chiefly to Professor Nehring, who has for ne twenty years devoted special attention to the fauna of löss. In my account, therefore, I shall take him for my ide, referring the reader for fuller details than are ssible here to Dr. Nehring's interesting work.[1]

The researches of this palæontologist have established fact that, in Western and Middle Europe an arctic fauna ıaracterised especially by the presence of the lemming) s succeeded in time by a fauna which included jerboas, uched marmots, tailless hare, little hamster-rat, and ıers—an assemblage of species such as we now find living the steppes of Eastern Russia and Western Siberia. This its turn gradually gave place to a temperate forest-fauna. ıe evidence of this succession is not derived from the s only, but is met with also in many cavern-deposits of ntral Europe.

The arctic fauna referred to includes the following:—
orquated lemming, Siberian lemming, mountain-hare, arctic x, reindeer, musk-ox, glutton. Along with these occur now ıd again various kinds of field-mice, as also ermine, weasel, olf, and common fox. A number of northern birds have ft their remains on the same geological horizon, such as armigans (*Lagopus albus*, *L. alpinus*), buntings, snow-wls, ducks, geese, swans, and others—all of which are in ırmony with the arctic character of the mammalian fauna, nce the same species in our day visit the tundras of

Ueber Tundren und Steppen der Jetzt- und Vorzeit, &c., 1890. This work ves a full list of papers, &c., dealing with the subject. Since 1890 Dr. hring has continued his interesting researches, some reference to which ll presently be made.

Siberia abundantly in summer. Molluscs are not common in the lemming-beds. At Thiede, where one of the most notable exposures of this stage occurs, Nehring obtained only a few scattered specimens of *Succinea oblonga, Helix pulchella, H. tenuilabris*, and *Pupa muscorum*. Vegetable remains are likewise sparingly met with. Thin peaty layers, however, occasionally appear, consisting apparently of the remains of scraggy brushwood and grasses. These interesting relics of tundra-conditions have now been traced over a wide area. The lemming, for example, formerly ranged from Southern England and Central France, through Belgium and Middle Germany into Russian Poland and Austria. Nor can we doubt that it was native in those regions, and not a mere temporary immigrant. This may be inferred not only from the manner in which the remains occur in the Pleistocene deposits, but from the large numbers of individuals which are represented in certain places. Thus the skeletons of hundreds occurred at Thiede, Zuzlawitz, and Neutitschein —the specimens including both full-grown and young individuals. That the lemming was actually indigenous in what is now temperate Europe is further shown by the character of its associates, and by the fact that these also bred in the same regions. Thus at Thiede Nehring found in close connection with the remains of lemmings two well-preserved skeletons of arctic fox with milk-teeth. As this animal breeds in June, it is obvious that the two young foxes must have died in summer.

The next succeeding stage is characterised by an equally well-marked fauna, which exactly recalls that of the subarctic steppes of Russia and Siberia. That fauna included jerboa (*Alactaga jaculus*), pouched marmots (*Spermophilus rufescens, S. mugosaricus, S. fulvus*), bobac or Polish marmot (*Arctomys bobac*), pika or tailless hare (*Lagomys pusillus*), little hamster-rat (*Cricetus phæus*),[1] various voles (*Arvicola gregalis, A. œconomus*); small steppe-lemming (*Myodes lagurus*), corsac (*Canis corsac*), caragan fox (*Canis caragan ?*), manul-cat (*Felis manul ?*), saiga (*Antilope saiga*), dzeggetai (*Equus nemionus*), and wild horse (*Equus caballus ferus*). Along with this true steppe-fauna occur the remains of other animals which are

[1] Nehring, *Jahrb. d. k. k. geol. Reichsanstalt*, 1893, Bd. xliii. p. 179.

restricted to the steppes ; and with these were associated ious extinct forms, which there is every reason to believe l a similar range. Prominent amongst this group were mammoth and the woolly rhinoceros. Both these animals m to have had a wide range, and wandered over Middle rope while that region was occupied by the jerboa and its geners. It is certain, indeed, that they even visited the tral parts of our Continent during the preceding Arctic ge. They abounded in Europe, however, during the eppe period,' and ranged over a vast area in Central Asia l Siberia. Amongst their congeners in Europe were sk-rat (*Myogale*, sp.), mole (*Talpa Europæa*), marsh-x (*Felis chaus*), lion (*F. spelæa*), a northern variety, logous to the northern form of the tiger which in our own is met with in Southern Siberia, and is not unknown also he steppe-lands of Turkestan ; hyæna (*Hyæna spelæa*), bably a northern variety of the spotted hyæna of South ica ; wolf (a large form), common fox, ermine, weasel, mon badger, common hamster (*Cricetus vulgaris*), voles *vicola amphibius, A. arvalis*), steppe-porcupine (*Hystrix sutirostris*), hares (*Lepus timidus, L. variabilis*), reindeer, ge deer (referred to the Wapiti (*Cervus Canadensis*), or to *eustephanus* of Central Asia) ; another great deer (*C. eury-os*) met with occasionally, but never associated with the re typical steppe-species, such as jerboa ; musk-ox now l again (probably only a winter visitor), urus, bison (*B. ropæa*, or its fossil precursor, *B. priscus*), and ox (*Bos tau-*). Remains of various birds occur also in association with steppe-fauna, such as great bustard (*Otis tarda*), swallow *irundo rustica*), finch (*Fringilla*, sp.), larks, wagtails, and ler small forms ; ducks (*Anas boschas, A. crecca*), moor-fowl, —all in our own day still met with in the steppe-lands of st Russia and West Siberia. Traces of reptiles are seldom n in the löss, and it is well known that in the steppe-lands to-day reptiles are of infrequent occurrence. Remains frogs and toads are not unknown in lössic accumu-ions, and bones of fish have likewise been detected. No mplete or even approximately complete skeleton of a fish, wever, has yet been found—only an occasional jaw or rtebra. Molluscs, on the other hand, sometimes abound. At

Thiede the following have been met with :—*Pupa muscorum, Chondrula tridens, Cionella lubrica, Patula ruderata, P. rotundata, Helix striata, H. hispida, H. tenuilabris, H. pulchella, H. hortensis, H. obvoluta, Hyalina radiatula, Succinea oblonga, Limnæus pereger, Clausilia parvula, Pisidium pusillum.* Some of these, it will be observed (such as *Helix hortensis*) cannot be considered as typical steppe-forms, but are denizens of wooded regions. But, as Nehring points out, in the steppe-lands of East Russia and South-west Siberia oases of forest and brushwood make their appearance, and the occurrence, therefore, of the snail-shells in question is not out of keeping with steppe-conditions. Neither does the presence of a few isolated fresh-water shells (*Limnæa, Pisidium*) tell against such conditions, for the empty shells, which are of small size, might readily have been carried by wind from the bed of some dried-up or partially dried-up water. At Westeregeln Nehring obtained only a few shells associated with the steppe-fauna of the löss—the most common being forms that now live in dry treeless regions.

The löss of Franconia has yielded remains of the true steppe-fauna, associated with which occur some twenty species of shells [1]—the general facies of which suggests somewhat cold climatic conditions, and is in keeping with that of the molluscan fauna of Thiede and Westeregeln. In the lower reaches of the valley of the Main the löss has likewise yielded relics of a steppe-fauna along with a number of animals which in other regions are associated with the same fauna. The list given by Dr. Kinkelin [2] includes mammoth, woolly rhinoceros, horse, Irish deer (?), reindeer, hyæna, wolf, hamster (*Cricetus frumentarius*), tailless hare, vole, marmot. The most common shells are *Pupa muscorum, Succinea oblonga, Helix hispida,* and *Vallonia costata.* Fresh-water shells now and again occur, but they are not common. A similar molluscan fauna characterises the younger löss of the Rhine and many other regions—the conditions indicated by the shells being somewhat sub-arctic or cold-temperate. If this is true of West-central Europe, it is equally true of the

[1] F. Sandberger, *Verhandl. d. phys.-med. Ges. in Würzburg, N. F.* Bd. xiv. 1879. See also *Prehistoric Europe*, p. 60.
[2] *Abhandl. z. geol. Specialkarte v. Preussen*, &c. Bd. ix. p. 728.

ions farther east. Thus in Moravia the general facies of Pleistocene molluscan fauna is northern and alpine, while existing fauna is rather South-east European. According ?rofessor A. Rzehak,[1] the northern forms still living in Moia must be looked upon as relics from Pleistocene times. ›fessor Nehring calls attention to Dr. Böttger's account of molluscan fauna of the Russian Governments of Poltawa, 'm, and Orenburg, and points out that the steppe-fauna he löss of Middle Europe is quite in harmony with that he Russian steppe-lands, as regards the majority of vertetes and molluscs alike. The steppe-lands in question are ɜrsified here and there by streams, patches of forest and shwood, and by hills and rocky areas—and are not the formly treeless, monotonously flat and streamless tracts ;hey have sometimes been described.

A general review of the evidence adduced, especially by ıring and Woldřich,[2] leads to the conviction that in ldle Europe a steppe-fauna gradually replaced the ıming and its arctic associates, just as that steppe-fauna ;, in its turn, eventually succeeded by a forest-fauna, bracing such forms as stag, roe-deer, squirrel, pine-marten, d cat, lynx, &c. Amongst the thousands of fossils ained by Nehring from the sections at Thiede, which has visited some 300 times, not a single trace of any ;hese forest-forms was met with in association with the ppe-fauna. It is only in the uppermost part of the löss l in the recent alluvia that they make their appearance. d similar results have been obtained from a study of the 'e-deposits, as in the rock-clefts of Zuzlawitz near Winter-g in the Bohemian Forest,[3] in the caves of Moravia, ich have been studied by Dr. Kriz,[4] and in the rock-ılter of the Schweizersbild, to which reference has already ɜn made. In all these caves we find the succession of ındra-, Steppe-, and Forest-faunas clearly marked. Not ıt there is any sharply-defined line separating one fauna

[1] *Verhandl. d. naturf. Vereines in Brünn*, Bd. xxvi. p. 73.
[2] *Sitzungsb. d. kais. Akad. d. W., math.-nat. Cl.* 1880, p. 7; 1881, p. ; 1883, p. 978; *Mittheil. d. anthrop. Gesellsch. in Wien*, 1881, p. 8; 2, Heft 3 and 4.
[3] Dr. J. N. Woldřich, *op. et loc. cit.*
[4] *Jahrb. d. k. k. geol. Reichsanstalt*, Bd. xli. p. 534; xlii. p. 596.

from another. On the contrary, there would appear to have been gradual replacement. Thus the little lemming (*Cricetus phæus*), which pertains properly to the steppe-fauna, is sometimes found associated with the torquated lemming—a tundra-form, but neither ever accompanies the forest-fauna. At Schweizersbild, for example, the torquated lemming occurs side by side with *Cricetus phæus* and other steppe-animals. In the Moravian caves, in like manner, the layer with steppe-forms contains in its lower portions representatives of the tundra-fauna, while towards the top some forest-forms make their appearance. We may safely conclude, therefore, that Middle Europe has passed successively through tundra- and steppe-conditions. It must not be supposed, however, that such changes progressed with any regularity. On the contrary, it is obvious that tundra-, steppe-, and forest-conditions may well have obtained contemporaneously in different parts of the Continent. It is not even affirmed that all tundra-lands subsequently became steppes. On the contrary, such regions, under improving climatic conditions, would often be gradually converted into forests. Nor is it to be supposed that during the prevalence of steppe-conditions in any region forests were entirely wanting there, but, as Nehring remarks, they must have been very meagrely developed. It was only in later times that they gained the ascendency in Central Europe.[1]

Human remains and relics have been obtained again and again from various depths in undisturbed löss. The famous Eguisheim skull, for example, came from the löss of the Rhine. Very interesting are the finds of what appear to have been old camping-stations of Palæolithic Man. Thus Professor Ecker records the occurrence in the löss at Munzigen, in Baden, of a dark 'Culturschicht' containing charcoal, flint implements, and rein-deer remains.[2] Similar finds have been made by Professor Nehring at Thiede,[3] and a number of like discoveries have rewarded the researches of geologists in the löss of the Danube and its tributaries. Count Wurmbrand, for example, records the occurrence in löss

[1] *Op. cit.* Bd. xliii. p. 195.
[2] *Verhandl. Berl. anthrop. Ges.* Bd. viii. p. 87.
[3] *Ibid.* Bd. x. p. 357; *Mittheil. d. anthrop. Ges. in Wien*, 1893, p. 204.

t Zeiselberg (on the right bank of the Kamp, near where that ver enters the valley of the Danube) of a dark-coloured bed harged with charcoal and worked flints, together with the emains of mammoth, horse, Irish deer, reindeer, &c. Again, t Joslowitz and Hollabrun, in the valley of the Thaya, the ame investigator detected at a depth of 98 ft. from the pper surface of the löss a thin intercalated layer, crowded ith charcoal fragments, and containing a number of rude int implements associated with the remains of mammoth, oolly rhinoceros, horse, ox, reindeer (?), and bear (*Ursus rctos* ?). Many of the larger bones were broken, and had ide patterns incised upon them.[1] At Stillfried in the valley the March (of which river the Thaya is a tributary), milar discoveries have been made by Dr. M. Much, under thickness of 55 ft. of undisturbed löss. The bones at this ace appear to have been chiefly those of mammoth. They ere accompanied by quantities of charcoal and ashes, and umerous worked flints, along with the nuclei from which iese had been struck.[2] Again, at the confluence of the eczwa and the March a similar 'relic-bed' was dis- overed in the löss, containing worked flints, bones, and ory, along with remains of mammoth, woolly rhinoceros, orse, ox, musk-ox, reindeer, elk, various deer, bear U. *arctoideus* ?), cave-lion, glutton, wolf, arctic fox, common ox, and mountain hare.[3]

Professor A. Makowsky describes the occurrence in the eighbourhood of Brünn of a dark or black bed (two to eight iches thick), at a depth in löss of twenty-five feet from the urface. It showed layers of large and small fragments of iarcoal separated by red baked clay. The bed was well ex- osed during the operation of digging out a cellar in the löss, id was found to extend over an area of thirty to thirty-six uare yards. No implements were seen, but many bones oc- urred, some partially burnt, others broken and splintered— e species represented being horse, rhinoceros, and hyæna.

[1] *Denkschr. der k. Akad. der Wissenschaften* (*math.-nat. Classe*), 1879, 165.

[2] *Mittheil. d. anthrop. Ges. in Wien*, 1881, p. 27.

[3] Dr. Wankel, *Correspondenzenblatt d. deutsch. anthrop. Ges.* Bd. xvii., 886; Karl Maschka, *Der diluviale Mensch in Mähren* (Neutitschein), 1886 cited by A. Makowsky in his paper; see following foot-note).

The coprolites of the latter were abundant. A fall of the löss took place, and in the tumbled mass a human skeleton was found. Although the actual depth at which this had been embedded was not ascertained, it could not have been less than six to en feet. Another skull was disinterred from the löss at Hussowitz, in the same neighbourhood. Again at Schlappanitz, five miles south-east of Brünn, human remains were found along with those of Pleistocene mammals (chiefly mammoth and horse) at a depth from the surface of eight feet or thereabout. In a brick-pit on the east side of the Urnberg abundant relics of another camping-place have been disclosed. Here, at a depth of thirty-two to forty feet in the löss, a dark-brown layer appeared, from which were obtained remains of mammoth, woolly rhinoceros, cave-bear, horse, bison, reindeer, and numerous small bones of some undetermined species. The material in which the bones were firmly embedded was impregnated with ash, and full of charcoal fragments. The bones themselves were more or less calcined and very brittle. At one place, upwards of forty feet from the surface, appeared a layer of charcoal, some ten square feet in extent, in which were found some sharply-angular stones (the size of one's fist). These were blackened as if by smoke, and might well have produced the marks of hacking which are seen on the bones.[1]

Enough has now been advanced to show that Palæolithic Man lived in Central Europe while the löss was being accumulated, and we may next consider the question of the origin of that remarkable deposit. This question has been much discussed, and many attempts have been made to account for the formation. There are only two explanations, however, that we need examine—for they alone can bear critical handling. By some geologists the löss is held to represent the flood-deposits of glacial times, while others maintain that it owes its origin to the action of wind—that löss, in short, is not an aqueous but a wind-blown accumulation. These opposing views appear at first sight to be quite irreconcilable the one with the other. And yet, as I shall try to show, they are not so mutually destructive as they seem to be. There is a large element of truth in both. Let us

[1] *Verhandl. d. naturf. Vereines in Brünn*, Bd. xxvi.

›r a moment recall the conditions that obtained in our Con-nent during a glacial epoch. A vast area in the northern ›gions is covered by an ice-sheet, while in the Alpine Lands nd the mountains of Middle Europe large glaciers occupy ll the great valleys, and in many cases deploy upon the low-rounds. It is obvious that the streams and rivers which ›caped from those glaciers must have flowed in larger olume than their present successors. And so, in like ıanner, vast bodies of water must have proceeded from the ›rminal front of the northern ice-sheet. With each re-ırring spring and summer wide areas in the low-grounds 'ould thus be subject to floods and extensive inundations. 'e may be quite sure that all these waters would be turbid -highly charged with the fine flour of rocks that resulted om glacial grinding. The enormous thickness attained by ıe ground-moraines and the fluvio-glacial gravels, and the ıst extent of such accumulations, bear emphatic witness) the intensity of glacial erosion. The boulder-clay which ccumulated underneath the ice, and the coarse gravel grit nd sand which were swept out farther by the fluvio-glacial 'aters we have already recognised—where now are the finer rained ingredients which the waters must have swept far eyond the glaciated tracts? It can hardly be doubted that ıese are represented by the löss. The geographical distri-ution of that deposit suggests as much, for it overspreads ıe very regions which must have been subject to periodical oods and inundations. Thus, it is strongly developed in all ıe great valleys that drain from the Alps; it extends from est to east in Middle Europe in obvious relation to the ›sition of the terminal front of the Scandinavian inland-ice; hile similarly in Southern and South-eastern Russia it ›vers all the low-grounds that lie outside the glaciated ›gions. It is not necessary to suppose that the materials f the löss consist exclusively of fine rock-flour derived from lacial grinding. The 'rock-rubble' that seems to have ›rmed almost everywhere beyond the ice-covered regions ıows that frost and melting snow were active agents of hange even at low levels. Each spring and summer during glacial epoch doubtless saw much rock-rubbish and soil lipping, sliding, and flowing down the valley-slopes into the

turbid rivers—the finer grained materials travelling often far enough before they came to rest in the slack waters and broad inundation-lakes of the low-grounds. Further, it is almost certain that the drainage systems must frequently have suffered interruption and modification owing to the great accumulation of the winter snows. Reference has already been made to Darwin's views on this subject, and to his suggestion that valleys might eventually become entirely filled with the blown snows of successive years, so as to compel the rivers in summer to rise in flood, and to reach levels which they might otherwise have been unable to attain. That such changes may have taken place again and again is no mere dream. On the coasts of Eschscholtz Bay, Northern Alaska, occur the well-known ice-cliffs which Kotzebue discovered so long ago as 1816. He describes them as consisting of 'masses of the purest ice, of the height of a hundred feet, which are under a cover of moss and grass.' He adds: 'An indisputable proof that what we saw was real ice is the quantity of mammoths' teeth and bones, which were exposed to view by the melting.' [1] Captain Beechey, in 1826, visited the same spot, and came to the opinion that the ice-cliffs had no existence—the cliffs in his opinion being composed of mud and gravel concealed under a casing of ice.[2] But in 1848, Mr. B. Seemann, the naturalist attached to Captain Kellett's expedition, substantiated Kotzebue's observation, and showed that the firm ice of the cliffs was overlaid by a bed of blue clay from which the organic remains were derived.[3] Since then the same coasts have been carefully examined by the officers of the U. S. Coast and Geodetic Survey, more particularly by Mr. Dall,[4] who found that the ice exposed in section in the cliffs is the seaward prolongation of a mass which passes inland, forming a broad ridge some two miles in width and 250 ft. high. 'The ice, in general, had a semi-stratified appearance, as if it still retained the horizontal plane in which it originally congealed. The surface was always soiled

[1] *A Voyage of Discovery into the South Sea and Behring's Strait*, vol. i. p. 219.
[2] *Narrative of a Voyage to the Pacific and Behring's Strait*, vol. i. p. 353.
[3] *Narrative of the Voyage of H.M.S. Herald*, 1853, vol. ii. p. 33.
[4] *American Journal of Science*, 1881, p. 104.

by dirty water from above. This dirt, however, was merely superficial. The outer inch or two of the ice seemed granular, like compacted hail, and was sometimes whitish. The inside was solid and transparent, or slightly yellow-tinged, like peat-water, but never greenish or bluish like glacier-ice.' There is no high land in the surrounding region from which a glacier might have come, 'and the continuity of the mossy surface showed that the ice must be quite destitute of motion,' while the occurrence of remains of mammoth and other animals in the clay that overlies the hummocky and uneven surface of the ice proves the latter to be of great antiquity. These remains represent, besides mammoth, horse, elk, reindeer, musk-ox, bison (*B. crassicornis*), and bighorn (*Ovis montana*), and are abundant in the clay, which in places gave forth 'a strong peculiar smell as of rotting animal matter, burnt leather, and stable manure combined.' Certain dark pasty spots in the clay, indeed, suggested to Dall that 'these might be remains of the soft parts of the animals.' There cannot be any doubt, therefore, that this remarkable sheet of dead ice must date back to Pleistocene times, and is obviously of the same origin, Dr. Penck remarks, as the frozen bottoms or grounds which are so commonly met with in the higher latitudes of North America and Asia. Since the mammoth and its congeners disappeared, no similar accumulation of ice has formed in that region—the dead ice is not being added to, but is gradually wasting away—and Dr. Penck is clearly right when he says that the ice-masses of Eschscholtz Bay belong to an older period, when the climate of those northern regions was considerably colder than it is to-day. The 'frozen grounds' of the far North are, in short, the equivalents in time of the old glacial phenomena of our temperate latitudes.[1] The ice-masses of Northern Alaska are not the relics of any glacier or ice-sheet, for we have no reason to believe that those tracts have ever been glaciated. They simply represent the drifted snows of glacial times which accumulated in valleys and depressions outside of ice-covered regions. Protected under a covering of alluvial matter, soil, and peat, they have, in those high latitudes, endured to the present day. Farther south, as in Middle

[1] *Deutsche geographische Blätter*, Bd. iv. p. 174.

Europe, similar masses of congealed snow must doubtless have accumulated, and may well have persisted for a long time after the Scandinavian *mer de glace* had melted away from the plains of Northern Germany. We are justified, therefore, in the belief that the drainage systems in the low-grounds of our Continent must frequently have been deranged by the presence of such congealed snow-drifts. And, judging from what may be seen in Siberia in our own days, we may further infer that with each recurring summer the flooded rivers of the Glacial Period, bursting their icy covering, must frequently have piled up its fragments into great dams, behind which the water would quickly rise and inundate wide areas. It cannot, in short, be doubted that the summer floods of glacial times must have been much in excess of any inundations that we can study now in these temperate latitudes. The lower reaches of all the great valleys opening out from glaciated regions, as well as the wide tracts that extended in front of the great northern *mer de glace*, would be more or less drowned in vast lakes of turbid water, over the beds of which a fine sediment of somewhat uniform character would be deposited. And such may well have been the origin of the löss-materials.

One cannot, indeed, but admit that in its horizontal distribution the löss follows closely that of the valley-gravels of Pleistocene times. Where these are well-developed the former appears in full force, where they are wanting there is a similar absence of löss. This fact alone, taken in connection with much other detailed evidence as to the occasional occurrence of intercalated beds of sand, &c., with the presence of fresh-water shells here and there, seems suggestive of a fluviatile origin. On the other hand, the prevalent absence of well-marked bedding and of intercalated sheets of unmistakable aqueous deposits, the paucity of fresh-water organisms, and the abundant occurrence of snail-shells and mammalian remains, appear to demand some other explanation than that of flooded waters. Again, the löss usually attains so great an elevation above the old river-gravels as to preclude the possibility of its formation as an inundation-silt. Thus at Passau, on the Danube, while the Pleistocene gravel-terraces do not rise higher than 35 to 65 ft.

above the river, the löss sweeps up to a height of 400 to 600 ft. So also at Mayence the old gravels do not exceed 230 ft. above the Rhine, while the löss attains nearly double that elevation. Similarly in Saxony the Pleistocene gravels of the Mulde occur at 100 to 150 ft. above the surface of that river, while the löss goes up to 330 ft.[1] Further, the peculiar distribution of the löss in certain regions is not what might have been expected had that accumulation been wholly of aqueous origin. On the other hand, all these appearances are readily accounted for by Baron Richthofen's theory, which attributes the formation of the löss to the action of wind. He believes it to be a dust-deposit heaped up by the wind during the prevalence in Middle Europe of what we may call a steppe-climate. The two theories are not antagonistic, the one is simply the complement of the other. The materials of the löss were no doubt, in the first place, abundantly spread by the flood-waters of the Glacial Period over the low-grounds of Middle and Eastern Europe, where at a later stage they were worked up by the wind, re-arranged, and re-distributed. Dr. Wahnschaffe, for example, has shown that north of the Harz the löss which cloaks the lower slopes has obviously been derived by atmospheric action from the löss of the adjacent plateaux. The latter contains no shells, while these are more or less abundant in the re-assorted löss.[2] The same re-distribution is well exemplified by the löss of Galicia, for example, where it is heaped up in certain valleys in accordance with the direction of the prevalent winds.[3] In Moravia a similar distribution is seen. Thus in the neighbourhood of Brünn it cloaks the slopes of the valleys, being banked thickly against the hills, and sinking gently down into the low-grounds, where it tapers off to a feather edge. It attains its greatest thickness, moreover, on the backs of hills that incline towards the

[1] Penck, *Archiv für Anthropologie*, Bd. xv. Heft 1.

[2] *Jahrb. d. k. preuss. geol. Landesanst. für* 1886, p. 253. Reference may also be made to Professor Brückner's interesting observations in the Alpine Vorland.' He shows that the löss and löss-lehm of that region are the result of the weathering of glacial silt. In deep cuttings the fluvio-glacial accumulation shows a much-weathered upper portion, which passes gradually upwards into yellow unstratified löss and 'löss-lehm' of the usual character. (*Vergletscherung des Salzachgebietes*, &c. p. 176.)

[3] Dr. Tietze, *Verhandl. der k. k. geolog. Reichsanstalt*, 1881, No. 2.

east or south, while on the northern or north-west slopes of the hills, which are exposed to the action of the prevalent north-west winds, it is wanting.[1] C. von Camerlander has observed in the valleys of the Sudetes in Moravia and Silesia that the löss is likewise restricted to one side of the valleys.[2]

Accepting these two theories of the origin of the löss as together containing the truth, let us briefly glance at the succession of changes which the löss brings before us. We shall suppose that a glacial epoch is drawing to a close and that the summer inundations are becoming less extensive. Wide areas of the low-grounds have been swathed in loam, and the regions abandoned by the flooded waters are gradually clothed with an arctic-alpine vegetation. At this stage Middle Europe is in somewhat the same condition as the broad tundras, or Arctic steppe-lands. These are for the most part boundless wastes of morass, preserving a wonderfully level surface for vast distances. In some places, however, they are marked by numerous undulations—by hills and valleys. The typical tundras are treeless, but towards their southern margin trees begin to appear in hollows and sheltered places. According to Middendorf, it is in the highest degree probable that the tundras are underlaid throughout by frozen subsoils, which is never the case with the true steppe-lands of more southerly latitudes. Such, then, must have been the appearance formerly presented by Middle Europe. The chief occupants of that region at the time in question were lemmings, mountain hare, arctic fox, reindeer, musk-ox, and glutton. In summer other animals, such as mammoth, woolly rhinoceros, wild horse, &c., as well as many birds, came as visitors. Extreme glacial conditions had passed away, but the climate was still cold and ungenial, and in winter snow fell more or less abundantly. And just as in high arctic regions great storms sweep before them snow and dust and sand, so we may readily believe that in Middle Europe similar snow and dust-storms must frequently have raged. The terrors of such snow-storms have been

[1] A. Makowsky, *Verh. d. naturf. Vereines in Brünn*, Bd. xxvi. p. 213. The author remarks that in Brünn the direction of the wind is between north and west for 206 days in the year, and is especially strong at the equinox.
[2] *Jahrb. der k. k. geolog. Reichsanstalt*, Bd. xl. (1890) pp. 213, 289.

graphically described by Middendorf, who tells us that the snow-covering of the tundras does not always spread as a relatively thin sheet over the ground, but is heaped up against cliffs and in hollows to almost incredible depths, where it becomes so hard beaten and pressed as readily to bear the weight of a man.[1]

How long these tundra-conditions endured we cannot tell, but, as we have seen, they are well represented by the organic remains of the löss and of not a few caves. It is obvious, in short, that the formation of the löss, as we now see it, began at a time when the lemming and its congeners ranged throughout Middle Europe. As the climate became less arctic the fauna gradually changed, until eventually an assemblage of sub-arctic species took possession, including jerboa, pouched marmots, bobac, pika, and others. Their presence shows that true steppe-conditions now prevailed. But Middle Europe was visited at this time by many other animals, as by mammoth and woolly rhinoceros. Some of these had already appeared in the preceding or tundra period, but they now became much more abundant. Wide treeless plains must have existed at this time, diversified here and there by smaller and larger oases of forest-land, and traversed in places by streams and rivers. The climate was like that now experienced in the sub-arctic steppe-lands of Eastern Russia and Western Siberia—regions which, like the tundras, are much exposed to wind action. In summer dust-storms are of frequent occurrence, while in winter snow and dust and sand drift tumultuously before the wind. We who live in temperate lands can have no adequate conception of the horrors of such storms. The air is darkened with vast volumes of dust, while sand and grit and even small stones are swept forward—coming to rest here and there in the lee of projecting rocks or in hollows and depressions which in this way are gradually filled up. Thus great taluses of sand and dust gather on the valley-slopes that are sheltered from the prevalent winds—the slopes that face in the opposite direction being swept bare. In winter the snow in like manner drifts before the wind, and in places buries the dust- and sand-heaps to great depths. When

[1] *Sibirische Reise*, Bd. iv. p. 388.

spring returns and the snow melts away the wind-blown materials are often overspread with vegetation, and in this way become 'fixed,' just as the case is with the sand-dunes in our own and many other countries. Again, the great snow-drifts now and again are buried under deep accumulations of dust and sand, and may thus endure from year to year. Nehring refers to a very suggestive observation by Borszcow, who describes the occurrence in one of the tributary valleys of the Ilek (a dry region) of what appeared to be an ordinary sand-heap. About a foot underneath the surface, however, he found a mass of granular firn-like snow which could easily be bored into, but a little deeper the mass was firm and solid like ice.[1] If the formation of perennial snow-heaps can take place so far south as this, how frequently, as Nehring remarks, must similar accumulations be formed in sheltered places in the Siberian tundras.

Sir John Richardson informed Lyell that in the northern parts of America, comprising regions now inhabited by many herbivorous quadrupeds, the drift-snow is often converted into permanent ice. 'It is commonly blown over the edges of steep cliffs, so as to form an inclined talus hundreds of feet high; and when a thaw commences, torrents rush from the land, and throw down from the top of the cliff alluvial soil and gravel. This new soil soon becomes covered with vegetation, and protects the foundation of snow from the rays of the sun. Water occasionally penetrates into the crevices and pores of the snow; but as it soon freezes, it serves the more effectively to consolidate the mass into compact ice. It may sometimes happen that cattle grazing in a valley at the base of such cliffs, on the borders of a sea or river, may be overwhelmed by drift-snow, and at length enclosed in solid ice, and then transported towards the polar region.'[2]

We may next note how frequently destructive to life are those snow-storms. In the year 1827 all the herds of the small Kirghiz horde, who wander between the Ural and the Volga, were driven by a snow-storm into the Saratow Government, where 10,500 camels, 280,500 horses, 30,480 cattle, and 1,012,000 sheep perished. These, no doubt, were domes-

[1] *Naturwissenschaftliche Wochenschrift*, Bd. v. 1890, p. 518.
[2] *Principles of Geology*, vol. i. p. 189 (10th ed.).

tic animals, and it may be said that wild animals could not be thus overtaken, for, knowing the signs of an approaching storm, they would readily escape to a place of shelter. Dr. Nehring, however, points out that the herds of the Russian-Siberian Steppes live in a half-wild state, and their instinct for self-preservation is as well developed as in wild animals. Nor are we without direct evidence that the wild denizens of the steppes and tundras now and again perish in snow-storms. According to Bogdanoff, the saiga-antelopes of the Volga Steppes were in 1830 driven by a snowstorm far from their wonted haunts, and many died. Again, we are told by A. G. Schrenck that in the tundras the wild reindeer with their young often perish in snow-storms. Professor Garman has drawn special attention to the great destruction of flocks and herds caused by the 'blizzards' of North America. Thus in the blizzard that swept over the Medicine-Bow and Elk-Mountain region a few years ago large numbers of cattle perished in places where they had vainly sought shelter—their bodies after the snow had melted being found huddled together. He believes the extraordinary heaps of skulls and bones of the bison that are met with here and there in North Colorado and Wyoming are the remains of herds which have similarly died in snow-storms.

One can hardly doubt that the various conditions referred to above as characteristic of a steppe-country also obtained in Middle Europe during the löss period, when jerboas and their congeners abounded, and when Palæolithic men hunted the mammoth and the reindeer, and huddled round camp-fires on the plains, or sheltered under rocks and in caves. We can readily understand, therefore, why the organic contents of the löss should be chiefly terrestrial—mammoth-bones and snail-shells. As dust and sand were drifted about by the winds, land-surface after land-surface would in places become successively buried. The grasses, however, would tend to fix the fertile dust-deposits and prevent the formation of dunes to any large extent. Some regions, however, would appear to have been very sparsely clothed with vegetation. The heaps and sheets of morainic gravels and sand that mark the southern limits reached by the Scandinavian *mers de glace* have yielded at and near the surface quantities of

rudely triangular stones, the polished surfaces of which betray the action of drifting sand. These are the well-known 'Dreikanter' or 'Pyramidalgeschiebe' of German geologists, which appear to have been first observed by Professor G. Berendt, and the mode of their formation to have been first ascertained by Dr. A Mickwitz.[1] But although heaps of barren siliceous sand might long remain without a vegetable covering, this would hardly be the case with the finer dust-deposits. Moistened by the melting snows in spring, they would often be quickly overspread with vegetation. In short, the low-grounds of Middle Europe at the period in question must have formed typical steppes—entirely devoid neither of wood nor water, but traversed by broad rivers with their tributaries, along the margins of which trees may well have flourished more or less abundantly.

As wind has admittedly played a most important part in the formation of our löss, we can hardly doubt that the animals whose remains now and again occur so abundantly in that deposit must frequently have perished in snow-storms. The possibility of this having happened was certainly, as we have seen, in Lyell's mind when he reflected on the information supplied to him by Richardson. But Leopold von Schrenck would seem to have been the first to realise the conditions under which the mammoth and its congeners were entombed in the frozen earths of the far North.[2] That these

[1] Berendt, *Jahrb. d. k. preuss. geolog. Landesanstalt für* 1884, p. 201; Mickwitz, *Mém. de la Soc. Impér. Minéralog. à St.-Pétersbourg*, t. xxiii. 1886; F. E. Geinitz, *Arch. Ver. Nat. Meckl.*, 1886. See also De Geer, *Geol. Fören. i Stockholm Förh.* Bd. viii. p. 501; Wahnschaffe, *Zeitschr. d. deutsch. geol. Ges.* Bd. xxxix. p. 226; W. Dames, *ibid.* p. 229; A. Heim, *Vierteljahrsschr. d. Züricher naturf. Ges.*, 1888. An excellent account of the wind-polished stones of the Lybian Desert, with illustrations, is given by Professor Walther, *Abhandl. d. math.-phys. Classe d. k. Sächsischen Ges. der Wissenschaften*, Bd. xvi. p. 445. These *Dreikanter* are not confined to the low-grounds of Germany. M. Fontannes has recorded them from the Pliocene alluvia of the Rhone Valley, but attributes them rather to the action of water than of wind. (*Bull. Soc. géol. de France*, 1885–86, p. 246.) Herr T. Fegræus also mentions their occurrence in Gotska Sandö (an islet near Gottland in the Baltic), and has no doubt that they owe their polishing to the action of the wind. (*Geol. Fören. Förh.* (1886) Bd. viii. p. 514.) They occur likewise in Schleswig-Holstein in places where loose sands are exposed to the action of the wind. This is specially the case in exposed heath-lands—the smoothed surfaces of the stones being orientated in relation to the direction of the prevalent winds. (Dr. C. Gottsche, *Sedimentär-Geschiebe der Provinz Schleswig-Holstein*, 1883, p. 6.)

[2] *Bull. de la Classe Phys.-math. de l'Acad. Impér. des Sciences de St.-Pétersbourg*, t. xvi. p. 147; *Mém. de l'Acad. Impér. &c.* t. xxvii. (1880) p. 39.

were frequently the victims of great snow-storms there can be little doubt, and Professor Nehring has applied this theory to explain the occurrence of the abundant bone-accumulations in the löss of the caves and the rock-clefts and shelters of Middle Europe.[1] He points out, however, that in a steppe country masses of drift-snow could not persist for any time without a protecting cover of dust and sand. And he refers to Borszcow's observations in support of his contention that drift-snow enveloping the bodies of animals might thus have endured for long periods. The enormous quantities of mammalian remains that lie buried in the 'frozen soils' of Northern Siberia and North America show that formerly the climate of those regions was not so cold as it is now. Coniferous forests and birch-woods extended farther northwards than they do in our day. But the open and flat character of the whole region exposed it to the full sweep of the wind—so that dust-storms in summer and blizzards in winter must always have played an important *rôle*. Nor is it hard to believe that in spring-time when thaw ensued great snow-banks must often have become buried under superficial débris in the manner described by Sir John Richardson. Indeed the structure of the frozen earths of Siberia shows that they must have originated in some such way. Layers of frozen earth alternate with sheets of ice, and the presence in the latter of the well-preserved bodies of mammoth and woolly rhinoceros indicate that we are here dealing with accumulations of Pleistocene age. It is not necessary, therefore, to suppose that all the mammalian bones met with in the superficial deposits of the far North are the remains of animals which somehow got frozen into river-ice in lower latitudes and afterwards were transported toward the polar regions. The mammoth and its congeners, as we shall learn, lived all the year round in Northern Siberia, when the cold was not so intense as it is now.

Having indicated what appears to have been the origin of the European löss, another question arises. What relation does this löss present to the glacial accumulations of the Alpine Lands and Northern Europe? We have seen that the

[1] For references to many such finds consult H. H. Howorth's *The Mammoth and the Flood*, chap. vii.

Pleistocene river-gravels of the Rhine and other valleys are clearly overlaid by it. How, then, does it behave with regard to the moraines and fluvio-glacial detritus? Some years ago Dr. Penck showed that while löss overlies the plateau- and high-level gravels of the Alpine Lands, it is never seen resting upon the low-level gravels. Similarly, while it sweeps over the great moraines of the outer zone it nowhere covers the moraines of the inner zone. In like manner it avoids the region occupied by the moraines and fluvio-glacial gravels and sands of the lesser *mer de glace* (*i.e.* the third ice-sheet) of Northern Europe, while it spreads over the surface of the older morainic accumulations that lie to the south.[1] More than this, Penck has shown that in the neighbourhood of Munich löss is intermediate in age between the accumulations of the first and those of the second glacial epoch; while Brückner finds it occupying an interglacial position between the second and third series of moraines in the Salzach region. Penck and Brückner agree[2] that it nowhere overlies the moraines of the inner zone, and the same conclusion has been reached by Du Pasquier and others. From these several observations we may infer with Professor Penck that the löss is in the main of interglacial age,[3] but that it is not confined to one interglacial horizon. When we get away from the Alpine 'Vorland' a similar succession presents itself. Thus, in the valley of the Rhine, between the Vosges and the Black Forest, the main mass of the löss is certainly of later age than the high-level terraces, but Dr. Schumacher has shown that these gravels in Alsace are underlaid by a yet older series of gravels with associated löss.[4] And a similar succession has

[1] *Archiv für Anthropologie*, Bd. xv. Heft 3 (1884).

[2] Brückner, *Vergletscherung des Salzachgebietes*, &c. pp. 63, 175; Du Pasquier, *Beiträge zur geolog. Karte der Schweiz*, 1891; *Mitteilungen der Grossh. Badischen geolog. Landesanstalt*, Bd. ii. p. 395; Steinmann, *ibid.* p. 745. See also O. Fraas, *Begleitworte zur geognost. Specialkarte von Württemberg* (*Atlasblätter Leutkirch und Isny*), 1882, p. 14; A. Baltzer, *Mitt. d. naturf. Ges. v. Bern*, 1885, Heft i.

[3] E. von Fellenberg assigns the löss (10 ft. thick) which occurs in Canton Bern, on the borders of the Birkeneggwald, to an interglacial horizon. It is overlaid by morainic materials (*Mitt. d. Naturforsch. Ges. Bern*, 1885, Heft 1).

[4] 'Die Bildung und der Aufbau des oberrheinischen Tieflandes,' *Mitt. d. Comm. f. d. geolog. Landes-Untersuch. v. Elsass-Lothringen*, Bd. ii. (1890).

been established for Baden by Professor Steinmann.[1] Schumacher recognises two varieties of löss—'sand-löss,' which is associated with ordinary fluviatile sand and gravel in the formation of terraces—and 'true löss,' which spreads like a sheet over the valley-slopes. The former he designates *Terrassenlöss*, the latter *Deckenlöss*. Both varieties are represented in the older and younger series of lössic accumulations. In the older löss at Achenheim a 'Culturschicht' occurs, consisting of charcoal-fragments and ash, commingled with which are mammalian bones (horse and ox) and rude stone implements. Many of the bones also have been shaped and cut to form implements or weapons. The löss at Eguisheim, near Colmar, in which Faudel discovered a human skull,[2] is believed to be of the same age as that of Achenheim. The terrace-löss, according to Schumacher, is an aqueous deposit. This is indicated not only by its constant association with fluviatile gravels, but by its bedding, which shows alternate lines and layers of finer and coarser-grained materials. Now and again snail-shells, often broken, occur, but are arranged in thin lenticular layers. Similarly thin lines and occasional thick beds of pure sand appear intercalated in the löss, while throughout the whole mass fresh-water shells are met with. The 'sheet-löss' (*Deckenlöss*) on the other hand is not stratified, and contains no fresh-water shells, while land-shells are common. In short, it is a true wind-blown accumulation. Now since löss occurs on two separate and distinct horizons in the Rhine Valley, Dr. Schumacher believes that a steppe-like climate has occurred at least twice in that region.[3] He points out further that the lower

[1] 'Ueber die Gliederung des Pleistocän im badischen Oberlande,' *Mitt. d. Grossh. Badischen geolog. Landesanstalt*, Bd. ii. p. 745.

[2] *Bull. de la Soc. d'Hist. nat. de Colmar*, t. vi. p. 283; *Bull. de la Soc. géol. de France*, 2e sér. t. xxiv. p. 36.

[3] At Vöklinshofen in Upper Alsace mammalian remains occur embedded in sand and löss in the clefts, crannies, and cavities between tumbled masses of sandstone. The fauna includes mole, common marmot, spermophile, dormouse, water-rat, field-vole, lemming, torquated lemming, mountain-hare, wolf, fox, cave-bear, brown bear, glutton, weasel, hyæna, cave-lion, lynx, wild-cat, wild-boar, mammoth, woolly rhinoceros, horse, reindeer, wood-mouse, megaceros, ibex, stag, chamois, oxen (*Bos primigenius*, *B. taurus*). Here we have representatives of the arctic or tundra-fauna, such as lemmings, and of the steppe-fauna, such as spermophile. Some of the other forms, as we have seen, are frequently met with in the tundras, while others, again, are often encountered in the subarctic steppe-lands. (See Schumacher and Döderlein, *Mitt. der*

gravel-terrace is not entirely devoid of a covering of löss, but is in places overlaid with a continuous sheet of that accumulation.[1] Both he and Steinmann,[2] however, are of opinion that the chief mass of the löss of the Rhine Valley is intermediate in age between the formation of the high- and the low-level terraces.

To what extent each of these 'horizons' of löss may be represented in the low-grounds of Middle Europe we are not at present in a position to say. But, as the materials of the löss are for the most part of glacial origin, it is obvious that such accumulations must have been formed during each successive advance of the Alpine glaciers and the great northern ice-sheet. It remains to be seen, however, whether tundra- and steppe-conditions were repeated as each glacial epoch passed away. The evidence supplied by the Rhenish löss shows that steppe-conditions certainly obtained for a long time after the close of the second glacial epoch. Then followed the third glacial epoch, and after it had passed away tundra- and steppe-faunas again appeared, as is proved by the presence of their remains in the rock-shelter at Schweizersbild. It seems probable, therefore, that the wind-blown löss of the low-grounds of Middle Europe does not belong exclusively to the close of the third glacial epoch. With each successive advance and retreat of the *mers de glace*, we may believe that the physical conditions in the extraglacial tracts would to some extent be repeated. In other words, tundra- and steppe-climates may well have appeared again and again during the protracted Pleistocene period.

Be that as it may, it is quite clear that a steppe-fauna existed in Central Europe after the formation of the moraines of the 'inner zone' and the deposition of the fluvio-glacial accumulations of the lesser *mer de glace* of Northern Europe. It is also clear that this steppe-fauna gradually vanished, and was eventually replaced by a forest-fauna.

Thus, an examination of the Pleistocene deposits occupy-

Commission f. d. geolog. Landes-Untersuch. v. Elsass-Lothringen, Bd. i. p. 123; Bd. ii. p. 75.)

[1] *Mitt. der Comm. f. d. geolog. Landes-Untersuch. v. Elsass-Lothringen*, Bd. iii. p. xxxviii.

[2] *Mitt. d. Gr. Badischen Geolog. Landesanstalt*, Bd. ii. p. 399.

ing the extraglacial regions of the Continent leads us to the conclusion that they are the equivalents in time of the glacial and interglacial series. It is true that we cannot yet attempt to correlate bed with bed over the whole Continent. The climatic changes of the earlier Pleistocene were so marked, and the representative deposits are so well-developed both in glacial and extraglacial tracts, that there is less difficulty in correlating these. But when we come to the later stages —to the epoch of the last Baltic glacier and the subsequent chapters of the history as contained in the peat-beds and raised-beaches of North-west Europe—it is very hard indeed to say what deposits in the low-grounds of Middle Europe must represent those stages. We are not, however, without some suggestive evidence, which will doubtless grow in volume as observations are extended. Let it be remembered that the last Baltic glacier was contemporaneous with the district ice-sheets of the British mountain-tracts, and with the larger glaciers of the so-called 'first postglacial stage' in the Alps. To this stage ought probably to be assigned the final development of tundra- and steppe-conditions in Middle Europe—the steppe-conditions continuing for some time after the glaciers had commenced to retreat. Thereafter followed the epoch which is represented by the peat-bogs with their buried trees and the raised-beaches of North-west Europe, an epoch which, it will be remembered, was in its turn succeeded by a partial relapse to cold and wet conditions, marked by the re-appearance of small valley-glaciers in Scotland and by the renewed advance of glaciers in the Alps ('second postglacial stage'). It is in the peat-bogs and alluvial deposits of Middle Europe that we must look for evidence of the contemporaneous changes which affected those regions. Nehring, Liebe, Woldřich, and others have shown that forest-conditions followed the disappearance of the steppe-climate in Middle Europe, and were thus in all probability contemporaneous with the forest-conditions that obtained in North-west Europe after the fourth glacial epoch had passed away. Traces of that great forest-growth are abundantly met with not only in North-western but in Middle and Western Europe. Thus in the numerous peat-bogs of Auvergne and the Central Plateau of France large

trees are of common occurrence. In those of the basaltic plateau of Cézallier, which occur at heights ranging from 3,400 ft. to 4,750 ft., appear enormous trunks of pine, oak, beech, and cherry-tree, which are utilised by carpenters and cabinet-makers. There are no forests now in that region, and the cherry-tree could not live there under present climatic conditions.[1] Similarly in Southern Russia abundant evidence remains of former extensive forests. Professor Dokuchaev tells us that the forests of the Vorskla (Poltava District), which now scarcely cover an area of 12,000 to 14,000 dessiatines, extended in prehistoric times over at least 60,000 to 70,000 dessiatines.[2]

Our review of the evidence supplied by cave-deposits and by the Pleistocene accumulations of extraglacial regions, however rapid and incomplete, yet suffices to show that the deposits referred to are obviously contemporaneous with the glacial and interglacial series of North-western Europe, the Alpine lands, and other mountain-tracts. I have elsewhere discussed the story told by the Pleistocene faunas and floras of those extraglacial regions, and have shown that, while some of these are clearly indicative of genial conditions, others just as surely prove the former prevalence of arctic and sub-arctic climates.[3] When the history of the existing floras and faunas of our Continent comes to be worked out in detail, it will be found that these everywhere present us with relics of their Pleistocene predecessors.[4] Indeed, looked at broadly, we may still recognise in various parts of our Continent conditions which forcibly recall those of glacial and inter-glacial times. Thus in Scandinavia and the higher Alps we have perennial snow and ice, while the plants and animals of those regions and of the tundras and mountain-tracts of Europe generally remind us of the floras and faunas that formerly occupied the low-grounds of our temperate latitudes. Again, in the steppe-lands of South-eastern Russia, and even

[1] J. B. M. Biélawski, *Les Tourbières et la Tourbe*, Clermont-Ferrand, 1892, p. 112.

[2] *The Russian Steppes*, p. 26. A dessiatine is equal to 2·702 English acres.

[3] *Prehistoric Europe*, chaps. iii. and iv.

[4] The existence of these interesting 'relics' has long been known to naturalists, and many interesting examples might be cited from the writings of Heer, Saporta, Engler, Griesebach, Blytt, Krause, and others. But the subject is too wide to be entered upon here.

in the heart of the Continent, as in the Podolian plateau and in the dreary, dusty, and sandy flats traversed by the Theiss between Tokay and the Danube, we have survivals of old lössic conditions; while the genial interglacial climates of Middle Europe are approximately reproduced in the coast-lands of the Mediterranean.

CHAPTER XXXIX.

GENERAL SUMMARY OF THE EUROPEAN EVIDENCE.

Geographical and climatic conditions of Pliocene—Indications of approaching glacial period—Alternating cold and temperate epochs—Climax of cold attained in second glacial epoch—After climax is passed glacial and inter-glacial epochs successively decline in importance—Relation of Palæolithic Man to the Glacial Period.

SO many diverse threads of evidence have now been followed that it may be well at this stage of our inquiry to catch these up and weave them into one connected whole. Hitherto we have followed the analytical method; we shall now pursue the synthetical, and endeavour to acquire a connected view of those remarkable climatic and geographical changes which our Continent experienced in Pleistocene times.

Before the commencement of the Glacial Period Europe was in the enjoyment of a delightful climate—certainly more genial and equable than the present. This is clearly evinced by the character of the Pliocene flora, which appears to have been transitional between that of the preceding sub-tropical Miocene and the present. Not only was the Pliocene flora richer in genera than our own, but some of those genera were richer likewise in species. It was also singularly uniform, for the same forms seem to have ranged from Italy and the borders of the Mediterranean into the heart of France. And the fauna was in keeping with the flora. Some of the extinct types of earlier times still survived, such as the great pachyderms, *Deinotherium* and *Mastodon*, and with these were associated elephants, rhinoceroses, hippopotamuses, and many now extinct forms of ruminants, as well as species of bear, cat, hyæna, and other carnivores, including the sabre-toothed machairodus. Apes also were occupants of Europe in Pliocene times. As for the Continent itself, it had attained

nearly its present extent. Considerable areas, however, which are now dry land were then under water. Thus the low-grounds of Italy were still submerged—the valley of the Po forming a great arm of the sea, which likewise penetrated into the mountain-valleys of the Alps. The valley of the Arno, and Sicily to some extent, were similarly under water, and the like was the case with the lower reaches of the Rhone and wide tracts in the maritime districts of South-western France. The sea also covered the south and south-east of England, and overflowed at the same time a broad area in Belgium and a small part of Northern France.

When we consider the character of the terrestrial fauna and flora, and that of the contemporaneous life of the seas, we cannot doubt that in Pliocene times the waters that laved our shores were warmer than is now the case. Erelong, however, those genial conditions began to pass away, and our seas to become colder, until eventually the southern forms that had formerly stocked the British seas gradually vanished from our latitudes, and their places were taken by immigrants from northern and arctic regions. The presence in the North Sea of an arctic fauna shows that at this period of our history a cold current must have flowed southwards along our western shores, just as the Labrador Current in our own day washes the east coast of Canada and the New England States. We may be sure that under such conditions the flora and fauna of the land would become profoundly modified. Further, it may be inferred that snow-fields and glaciers had come into existence in our latitude, although we cannot tell to what extent the British area may have been glaciated. Scandinavia, however, would appear to have been sheeted in ice, for a great glacier then filled the basin of the Baltic, and traversed the south end of Sweden. How far south and south-west that glacier flowed has not been ascertained, but it may well have rivalled or even exceeded the great Baltic glacier of a later date. In the Alpine Lands striking evidence is forthcoming to show that all the great valleys of those regions were contemporaneously filled with glaciers that deployed upon the 'Vorland,' and there piled up their terminal moraines. The

limits reached by those glaciers indicate a depression of the snow-line of not less than 4,000 ft.

In time these cold conditions passed away, and were succeeded by a warm and genial climate. The southern half of the North Sea became dry land, and was traversed by the Rhine, which flowed through tracts covered with a flora approximating in character to that of the present. England was visited by elephants, rhinoceroses, and hippopotamuses, and great herds of various kinds of deer, as well as by bears, wolves, and other carnivores. Similarly in Central France forests of hornbeam, elm, oak, ash, box, and others clothed the land which supported a mammalian fauna like that of England. The genial character of the climate is still further evidenced by the fact that the valleys of the Alps on both sides of the chain were clothed with a flora no longer indigenous, but only met with farther south, on the shores of the Mediterranean and the Black Sea. The climate was certainly more genial and uniform than that which now reigns in Europe, but it was neither so warm nor so equable as that of the earlier Pliocene. The contrast between the north and the south of Europe became, in short, more marked than it had been in preglacial times. While dwarf palms still flourished in the Mediterranean Islands, and the Canary laurel with southern forms of oak occupied the south of France, the flora of Britain approximated to that of our own day. The vegetation was still abundant, and richer in forms than the present, but not equal in this respect to the flora of preglacial times. A number of the old Pliocene mammals also had disappeared, amongst them being mastodons, tapirs, and apes. The characteristic animals now were *Elephas meridionalis*, *E. antiquus*, *Rhinoceros leptorhinus*, *Hippopotamus major*, *Cervus Sedgwickii*, and others. Such was the character of the first interglacial epoch.

Again the climate changed, and it is noteworthy that the approach of the second glacial epoch was heralded by submergence in the area of the North Sea. Once more an arctic fauna immigrated into our waters and an arctic-alpine vegetation clothed the land. Perennial snows gathered in all the mountain-areas of Northern Europe, and gave birth

to innumerable glaciers. As time went on, the volume of ice increased to such an extent, that all the lands in our latitudes disappeared underneath one continuous far-extended *mer de glace*, which flowed south to the foot of the mountains of Middle Europe. In the far north-east the broad valley of the Petschora brimmed with ice, while glaciers appeared in the Ural mountains, in the Carpathians, in the Sudetes—in a word, in all the mountain-ranges of Middle and Western Europe. In the Alpine Lands the glaciers assumed gigantic proportions—exceeding those of the earlier glacial epoch—and denoting an average depression of the snow-line of not less than 4,700 ft. Nor were perennial snow and ice unknown in regions yet farther south, as in the Sierras of the Iberian peninsula, in Corsica, in the Apuan Alps and the Appenines, and in the mountains of the Turkish provinces. Regions that escaped glaciation were yet subject to severe frost, and often snow-clad, and when the summer thaws ensued, soils and subsoils were everywhere set in motion, travelling down hill-slopes and spreading over low grounds. At the same time the turbid rivers, swelled by the melting of the snow-fields, flooded their valleys, and inundated vast tracts in the plains and lowlands. The flora of Middle Europe at this time was essentially arctic-alpine, northern and arctic animals ranging south to the shores of the Mediterranean. That a cold northern current washed the west coasts of Europe can hardly be doubted. Iceland and the Færöe Isles each supported an ice-sheet, and bergs and floes drifted as far south and east as the Azores, while boreal and even arctic species of molluscs invaded the Mediterranean and flourished round the coasts of Sicily and Italy. And thus the second and greatest glacial epoch reached its culmination.

Eventually these strange scenes passed away. Gradually the snow and ice vanished from our present temperate regions—the ground as it became cleared being clothed with a tundra vegetation, and roamed over by reindeer, mammoth, woolly rhinoceros, musk-ox, and glutton. In Middle Europe steppe-like conditions appear to have succeeded for some time, but with the continuous improvement of the climate, a temperate flora and fauna by-and-by clothed and peopled

our Continent—the arctic, northern, and subarctic forms retreating up the mountains and returning northwards and eastwards to their old homes.[1] When this genial epoch reached its climax, a mild oceanic climate prevailed far into the heart of Europe. Britain now formed part of the Continent—the English Channel, and probably a large part of the North Sea, being dry land. The equable character of the climate is evidenced by flora and fauna alike. Hippopotamuses, elephants, rhinoceroses, great herds of cervine and bovine animals, and numerous carnivores ranged over the major portion of Europe. And with this teeming mammalian fauna Man was contemporaneous. Just as the land in those days extended farther into the Atlantic than is now the case, so in the south there would appear to have been one or more land-bridges over the Mediterranean, across which the southern forms passed to and fro. While those conditions endured we may well believe that a larger body of warm water flowed into the North Atlantic than is presently the case—bringing with it molluscs from southern latitudes, which invaded the Mediterranean, as their boreal predecessors had done in the preceding glacial epoch, when colder water washed the west coasts of our Continent. Towards the close of the epoch, however, a change set in—the coast-lands of the Baltic sank in the sea, and the low-grounds of Central and Northern Britain likewise became submerged. And so the second interglacial epoch passed away.

The advent of the third glacial epoch was heralded by the re-appearance of the arctic flora and fauna in the low-grounds of Northern and Middle Europe—their temperate congeners migrating as before towards the south. Step by step the climate deteriorated, until eventually another enormous ice-sheet, flowing outwards from the lofty Scandinavian plateau and the mountains of Britain, overspread a vast

[1] It is beyond a geologist's province to discuss the origin of the arctic flora. All we know is that it makes its first appearance in Pliocene deposits. Probably, as Heer maintained, it originated in the mountains of the Arctic zone in earlier Tertiary times, where it bore the same relation to the plants of the low-grounds as the present flora of the Alps does to that of the Swiss lowlands. See Heer's posthumous paper, 'Ueber die nivale Flora der Schweiz,' *Neue Denkschriften der allgemein. schweiz. Ges. für die gesammt. Naturwiss.* Bd. xxix. Abth. i. (1884).

region in North-western and Northern Europe. North Britain and Scandinavia appear to have been almost as deeply buried in ice as during the second glacial epoch, but the *mer de glace* did not reach the limits attained by its predecessor in North Germany and Russia. Once again the great glaciers of the Alps streamed out upon the 'Vorland,' but they, too, were less extensive than the earlier ice-flows; and the same was the case with the snow-fields and glaciers of the mountain-groups and ranges of other regions. The physical conditions that obtained in extra-glacial tracts during the second glacial epoch were now repeated. The formation of angular rock-débris went on apace, and under the influence of frost and thaw soils and subsoils slipped and flowed. With each recurring summer the turbid rivers rose in flood, and inundated wide districts, and gravel, sand, and silt were deposited in enormous quantities. When the rigour of the secular winter began to abate, and the snow-fields and *mers de glace* to retire from the low-grounds, the gradual retreat of the ice-king was followed by the advance of arctic plants and animals. Tundra-conditions now prevailed over all the wide districts of Middle and Western Europe, which had previously been visited by fluvio-glacial floods and inundations. The lemming and its congeners occupied what are in our days the most fertile regions of Western and Central Europe. Reindeer, mammoth, woolly rhinoceros, and Palæolithic Man were then the most conspicuous denizens of our Continent. And here, we may say, the third glacial epoch came to an end.

Gradually, as the conditions improved, the arctic forms migrated northwards, and were as gradually succeeded in Middle Europe by a steppe-flora and fauna. Britain appears to have again formed part of the Continent, and the western shores of Europe to have extended considerably farther into the Atlantic than is now the case. Hence for a long time relatively dry conditions prevailed over the central plains and low-grounds—the climate being somewhat extreme, and resembling that which now characterises South-east Russia and Western Siberia. The low-lying lands of Middle Europe were thus subject to dust-storms in summer, and to blizzards in winter. Meanwhile the forests were gradually extending

as the climate became less continental—the steppe-lands being more and more circumscribed as time passed. Eventually a true forest-fauna dominated in Middle Europe, as it probably had done for some time in other parts of the Continent. With these wide-spread forest conditions, the third interglacial epoch reached its climax. The climate was essentially temperate, but not so uniform and equable as that of preceding interglacial stages. The commingling of southern and temperate forms, so characteristic of these earlier stages, was no longer now a marked feature—the flora had become less rich and varied, while the great southern pachyderms and many of their congeners had vanished from the European fauna. *Hippopotamus* and *Elephas antiquus* did not apparently re-enter our Continent after the passing of the third glacial epoch. Possibly the disappearance of the land-bridges across the Mediterranean prevented their return from the south. The characteristic forms of this third interglacial epoch were jerboa, saiga, and their congeners, the mammoth and woolly rhinoceros, and, later on, the representatives of the forest-fauna. In Northern Europe the close of this epoch, and the advent of the next succeeding glacial epoch, were marked by submergence of the Baltic coast-lands, whereby open communication obtained across Schleswig-Holstein between the North Sea and the Baltic.

Snow-fields and glaciers now reappeared in Britain, district *mers de glace* occupying such regions as the Scottish Highlands. The coast-lands of Central and Northern Scotland were submerged to the extent of 130 ft. or thereabout, and in the west and north-west glaciers reached the sea, and calved their icebergs. Scandinavia and Finland at the same time were shrouded in ice, and a great *mer de glace* occupied the basin of the Baltic, and piled up its terminal moraines in Denmark, Schleswig-Holstein, and the northern provinces of Germany. The Scandinavian ice did not again become confluent with that of Britain, but the glaciers of Norway shed their bergs at the mouths of the great fiords. In the Alpine Lands, likewise, a recrudescence of glacial conditions supervened—the glaciers flowing often for considerable distances into the great longitudinal valleys, but never attaining the dimensions of those of the preceding glacial epoch. As

in earlier glacial stages, so now the formation of rock-rubble, and the distribution of gravel, sand, and silt in the valleys and low-grounds, were in active progress. The arctic-alpine flora occupied temperate latitudes, and the lemming and its congeners lived in Middle Europe. Towards the close of this glacial stage, submergence to the extent of about 900 ft. ensued in Scandinavia, and a cold sea with an arctic fauna communicated across Southern Sweden with the Baltic. This depression does not seem to have affected Denmark, between which and the most southerly part of Sweden there was land-connection. Palæolithic Man was still an occupant of our Continent, and hunted the reindeer at this time in the low-grounds of Switzerland. The climate was now again to change, and the fourth glacial epoch to come to an end.

Erelong in Middle Europe steppe-conditions supervened, and Palæolithic hunters followed the chase over wide, treeless districts in the low-grounds. Dust-storms and blizzards, as before, were experienced in the heart of the Continent, while vigorous forest-growth was developed in the west and north, and gradually encroached upon the steppe-lands, until at last it became dominant over the major part of the Continent. At this stage Britain again formed part of the Continent, which may have extended westward as far as the 100-fathoms' line. The Baltic was now a great lake—its surface rising some fifty feet above the present level of the sea. Yet another geographical change ensued, and Southern Sweden again sank under the sea. The fauna then living over the drowned land was no longer arctic, but indicative of more genial waters than now lave the coasts of that country. Britain about the same time became insulated, and the coast-lands of Scotland were submerged for fifty feet or thereabout. And so ended the fourth interglacial epoch, the close of which was marked by the advent of Neolithic Man, his Palæolithic predecessor having apparently vanished with the steppe-conditions which prevailed at an earlier stage of the epoch.

While these geographical changes were in progress the climate again became affected, and a relapse to glacial conditions supervened. Snow-fields gathered upon the higher mountains of the British Islands and small local glaciers

came into existence—here and there, as in the North-west Highlands, descending to the sea. The great forests of the preceding genial epoch decayed along the maritime tracts, and at the higher elevations of the interior, and the bog-moss and its allies flourished in their place. A cold wet period now prevailed, and destruction of forests and growth of peat-bogs became general. The changed climatic conditions would seem to have made their influence felt as far south as the Alps, and to have caused yet another advance of the glaciers, but of inconsiderable extent as compared with that of the preceding cold stage.

We now approach the end of the Pleistocene period. The oscillations of climate, so strongly marked in the earlier stages, became much less pronounced as the long period drew to a close. After the climax had been attained in the second glacial epoch, the cold stages following declined successively in importance, while the interglacial climates in like manner became less and less uniform and equable. The evidence supplied by the peat-bogs and calc-tufas shows that after the re-emergence of the British coast-lands from the depression indicated by the fifty-feet beaches, a second recrudescence of forest-growth supervened. The land at this time extended on all sides farther than is now the case, and the climate was drier than it had been during the immediately preceding stage. This is clearly shown by the fact that the peat-bogs had become desiccated and overspread by great forests—phenomena which were not confined to Britain, but characterised all North-western Europe.

Eventually, however, the sea again advanced and our coast-lands were submerged for twenty to thirty feet. The climate at the same time became more humid—and forest-growth was largely arrested, while peat-bogs and marshes extended their limits, occupying wide tracts over which woods had formerly flourished. Snow-fields then existed in our loftier mountain-ranges and gave birth to a series of small glaciers —whose moraines indicate a snow-line at 3,500 ft.

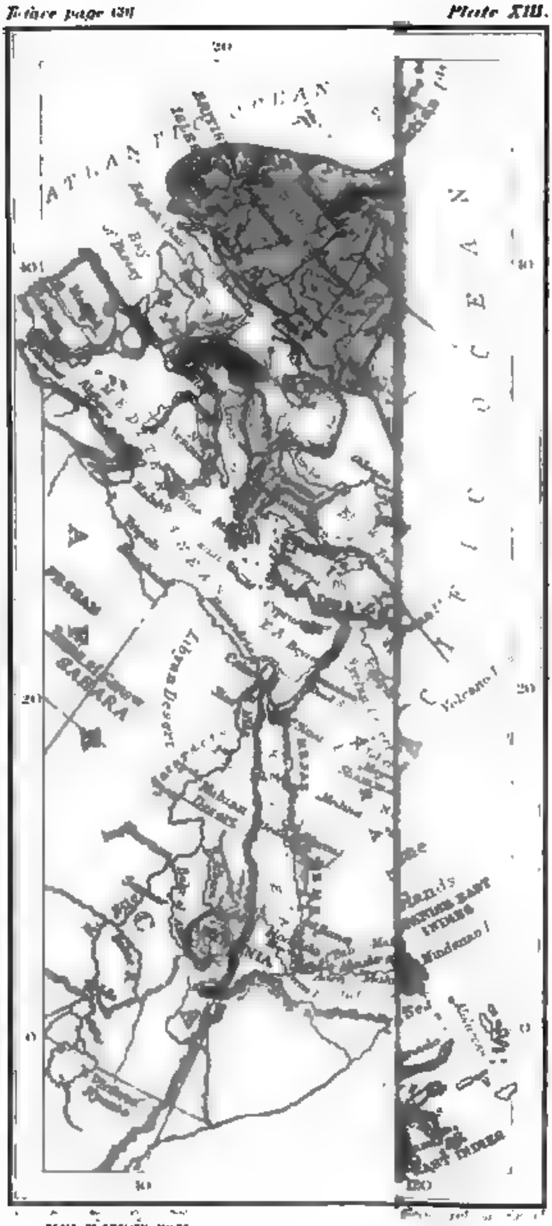
Finally, the sea retreated to its present position, the climate became somewhat drier, and our snow-fields vanished.

How far southward these later climatic oscillations extended we cannot yet tell. The latest stage of local glaciation

in Scotland has not yet been recognised in the Alps. If the conditions that induced the appearance of our latest glaciers were experienced as far south as Middle Europe they would probably induce another forward movement of the Swiss glaciers. But evidence of such a movement is not likely to be met with except in the loftiest valleys of the Western Alps.

So far as we can tell, Palæolithic Man made his earliest appearance in Europe in Pleistocene times, but there is no unequivocal evidence to show that he was an occupant of our area before the advent of the second glacial epoch. The cut bones obtained from the Tertiary beds of France and Italy may indicate his presence at an earlier period. The facts, however, have been otherwise interpreted, and we must await the discovery of more definite evidence before we can speak of Preglacial Man in Europe. Neither, so far as we know, was he an occupant of our Continent during the *Elephas-meridionalis* stage or first interglacial epoch. It is not until we reach the deposits of the second interglacial epoch (*Elephas-antiquus* stage) that we encounter abundant and unequivocal traces of Man, and these are characteristically represented by the Chellean or St. Acheul type of flint implements, which are met with so commonly in the old river-gravels of the Thames and the Seine. To what particular stage or stages of the Pleistocene period we are to assign the reindeer-hunters of Western Europe as a whole cannot at present be decided. It is highly probable that the cave-deposits of those regions do not all belong to one and the same horizon. Many caves, particularly those of Belgium and England, appear to have been abandoned before the third glacial epoch reached its climax—for they are sealed up by the morainic accumulations and rubble-drifts of that stage. And the same holds good with regard to not a few of the caves of France and Germany. But the evidence supplied by the rock-shelter of Schweizersbild shows that Palæolithic Man survived the third glacial epoch, and we know that he hunted the mammoth and the reindeer during the formation of the younger lössic accumulations of Middle Europe. It is on that horizon that we finally lose sight of him. Were we to judge from negative evidence we should

say that he never re-visited North-western Europe the third glacial epoch had passed away. During the c of that epoch he retired to Southern France—occupyin caves and rock-shelters of that country. There is no evi to show, however, that he again wandered northwards the climate improved. All we can positively assert is he passed eastward into Switzerland, and for a long lived the life of a hunter in the low-grounds watered b Danube. Not a trace of Palæolithic Man is forthco from any deposit that overlies the morainic and fluvio-g accumulations of the third glacial epoch in North-we Europe.



SCALE OF ENGLISH MILES

CHAPTER XL.

GLACIAL PHENOMENA OF ASIA, AUSTRALIA, ETC., AND SOUTH AMERICA.

Old glaciers of the Caucasus, Asia Minor, and Syria—Glaciation of the Himalayas—Traces of the Glacial Period in India—Glaciation of the Thian Shan, the Altai, and other elevated tracts of Central Asia—Vanished lakes—Löss —Marine deposits of North-west Siberia—Fresh-water beds and their fauna and flora—'Dead ice,' &c., of New Siberian islands—General remarks on Pleistocene of Siberia—Traces of ice-action in the Atlas—Evidence of former more humid conditions in North Africa, and in Palestine and Syria—Traces of ice-action in South Africa—Glaciation of the Australian Alps—Glacial phenomena in St. Vincent Gulf—Pleistocene alluvia of South Australia—Glacial phenomena in Tasmania—The glacier period of New Zealand—Traces of extensive glacial action in Kerguelen's Land and South Georgia—Stone-rivers of the Falkland Islands—Former glaciation of Patagonia, &c. —Evidence of old ice-action in other parts of South America.

IF Europe has experienced the utmost severity of glacial conditions we should expect that other regions of our hemisphere in the same latitudes should have passed through similar climatic changes. And Asia and North America we find have each had their Glacial Period. In the former continent the evidences of cold conditions have been encountered in most of the mountain-regions, but none of these has yet been studied in much detail. No proof is yet forthcoming of the occurrence of interglacial deposits, although there can hardly be much doubt that these will yet be recognised. At present, however, all we can point to are the relics of former glacial conditions. Reference has already been made to the fact that north of latitude 63° large glaciers have descended from the Urals into the valley of the Obi. The great chain of the Caucasus has likewise supported more extensive snow-fields and larger glaciers than are now encountered in that region. The evidence collected by Abich and others shows that the existing glaciers are confined to the upper reaches of the mountain-valleys, and are better

developed on the northern than on the southern slope of the chain. This, at first sight, seems to be out of harmony with the position of the snow-line, which descends on the south side for 1,000 ft. to 1,500 ft. below the level it attains on the northern flanks of the mountains.[1] But, as M. E. Favre remarks, the size of the glaciers depends less upon the position of the snow-line than upon the orographical features that allow of the greatest accumulation of snow. The snow may descend to a lower level on the south, but that difference is compensated for by the vast reservoirs of névé which drain towards the north, while those that open southwards are relatively small. The glaciers that descend to the north are therefore larger and flow farther than those on the opposite side of the chain—some of them being glaciers of the first order, for they reach levels of 4,600 ft. to 5,300 ft. below the limits of the snow-fields. Hence the terminal fronts of these northern ice-flows occur at heights above the sea ranging between 5,700 ft. and 7,500 ft., while the southern glaciers terminate at levels varying between 6,600 ft. and 10,480 ft. Similar differences obtained in glacial times—the northern glaciers, as shown by the presence of striated rocks, bottom and terminal moraines, and erratics, having descended to the plains for a distance in some cases of five miles from the foot of the mountains, while on the south side the glaciers would appear to have been of relatively inconsiderable importance.[2] It is noteworthy that no conspicuous valley-lakes, comparable to those of Switzerland, occur in the Atlas. This absence of lakes has sometimes been cited as an argument against the glacial origin of rock-basins. But, as we have seen, rock-basins are not always necessarily formed where glaciers have existed. If the gradient of the valley be too steep no rock-basin capable of containing a lake can be excavated. Again, not infrequently rock-basins have been formed and again filled up; and, so far as I can judge from the descriptions given of the valleys of the Northern Caucasus, this may well have been the case with them. The Caucasus

[1] The snow-line on the south side of the chain ranges from 9,600 ft. in the west to 10,500 ft. in the central parts, and 12,000 ft. in the east.

[2] E. Favre, 'Recherches géologiques dans la partie centrale de la chaîne du Caucase,' *Neue Denkschr. d. all. schweiz. Ges. für d. gesammt. Naturwiss.* Bd. xxvii. (1876) Abth. i.

is undoubtedly a region in which erosion goes on apace—and enormous quantities of detritus are carried down by destructive torrents. The lower reaches of the valleys and the plains at the foot of the mountains are described by Abich and others as being covered with great sheets of gravel and alluvial detritus, and one may readily believe, therefore, that many a rock-basin may in this way have been obliterated.

Passing into Asia Minor, we find, according to Palgrave, that the mountains of Trebizond and Erzeroum have at one time nourished considerable glaciers which have left their moraines in the valley of the Chorok.[1] The mountain-mass of Ardjèh Dagh (13,000 ft.) supports snow-fields and glaciers, but I can find no reference to any evidence of former and more extensive glaciation having been noted among the Taurus Mountains. Ararat (17,000 ft.), in like manner, has its snow-field and one diminutive glacier, but formerly it supported larger glaciers, as is shown by the presence of polished and striated rock-surfaces described by Dr. Wagner as occurring considerably below the level now reached by the ice.[2] Demavend (18,450 ft.), which overlooks Teheran, is clothed atop, like Ararat, with névé and ice, but no mention is made of glacial phenomena at lower levels.[3] Many years ago Sir J. Hooker described the occurrence of ancient moraines in the Lebanon[4] at a height of about 4,000 ft. above the sea, and more recently similar phenomena have been observed in that region by Oscar Fraas.[5] The same geologist tells us that the cave-deposits of the Lebanon have yielded remains of the Pleistocene mammals, such as *Felis spelæa*, *Ursus arctos*, *Rhinoceros tichorhinus*, &c. He likewise notes the occurrence of moraines and erratics amongst the mountains of Sinai, but his conclusions as to the former existence of glaciers in that region have been called in question by Prof. Hull and others.[6]

[1] *Nature*, vol. v. p. 144; vol. vi. p. 536.
[2] Cited by Reclus, *Géographie Universelle*, t. vi. p. 250.
[3] Dr. Th. Kotschy, *Petermanns Mitteilungen*, 1859, p. 49.
[4] *Natural History Review*, Jan. 1862, p. 11.
[5] *Aus dem Orient*. See also W. M. Thomson, *Journ. American Oriental Soc.* vol. x. 1880, No. 2.; and E. Hull in work cited in the following footnote.
[6] *The Survey of Western Palestine; Memoir on the Physical Geology and Geography*, &c. 1886, p. 114.

Of the glacial phenomena of the elevated plateaux and bordering mountain-chains of Central Asia we have little detailed knowledge. There is in the Himalayas, however, 'abundant and unmistakable evidence of a great extension of the glaciers at no very distant geological date, ancient moraines being found in many valleys of Sikkim and Eastern Nepaul at elevations of between 7,000 and 8,000 ft., and distinct traces of glacial action exist in valleys the lowest portion of which is not now more than 5,000 ft. above the sea. Moraines have been noticed by Colonel Godwin-Austen farther east in the Nága hills, south of the Assam valley, as low as 5,000 ft.; in the Western Himalayas perched blocks are found 3,000 ft. above the sea, and very large erratics have recently been noticed in the Upper Punjab at much lower elevations.'[1] It is obvious, then, that the Himalayas have passed through a marked glacial epoch. The contrast between past and present conditions is well brought out when we compare the former with the existing glaciers of one particular region. Thus, according to the late Mr. Drew,[2] the Sind Valley was at one time occupied by a glacier not less than forty miles in length. This is not much greater than the size attained by the largest of the glaciers that descends from the Karakoram, which is thirty-six miles long, but it contrasts strongly with the small separated glaciers that occupy the hollows of the mountains overlooking the head-waters of the River Sind.

No trace of recent glacial action has been met with in any part of Peninsular India, as indeed might have been expected, but the occurrence on the higher ranges of Southern India of Himalayan plants and animals would

[1] H. B. Medlicott and W. T. Blanford, *A Manual of the Geology of India*, Part I. p. 373; *op. cit.* 2nd edit. (1893) p. 14.

[2] *Jummoo and Kashmir Territories*, p. 220. See also a paper by Captain A. W. Stiffe on the glaciation of parts of the Jhelam and Sind valleys, *Quart. Journ. Geol. Soc.*, 1890, p. 66. Geologists who have visited the Himalayas are generally agreed as to the former greater extension of the glaciers, but some doubt has been expressed as to the mere presence of large erratics in the valley-bottoms at low levels being taken as proof that these low levels were formerly reached by the glaciers. It would appear that the rivers are subject to extraordinary floods, due to the formation of lakes in the upper reaches of the valleys by obstructions caused by landslips or glaciers, and to the sudden giving way of such obstructions. The violent floods produced in this way might readily carry down enormous quantities of coarse detritus and blocks. See *Manual of Geology of India*, Part II. p. 516.

seem to show that the climate of the peninsula was probably to some extent affected in glacial times. The inference is that the species referred to may have retreated in the first place from the Himalayas towards the equator, and subsequently, as the temperature increased, to the higher parts of the southern hills. Messrs. Medlicott and Blanford mention as examples the occurrence of a Himalayan rhododendron, of a wild goat allied to a Himalayan species, and of several Himalayan land-shells, on the Nílgiri and other southern Indian hills. These 'relics,' therefore, would seem to be analogous to the arctic-alpine colonies on the mountains of temperate Europe. The same geologists point out that the recent mammalian fauna is very meagre as compared with the wonderful wealth and variety of forms which flourished in India in preglacial times. And they think it most probable that the present impoverished aspect of the Indian fauna was due to the secular refrigeration that culminated in the Glacial Period.[1] A similar tale is told, as we have learned, by the European mammalian fauna, and the same holds good for America. 'We live,' as Mr. Wallace remarks, 'in a geologically impoverished world, from which all the largest and fiercest and strangest forms have recently disappeared'—a change which he thinks was brought about by the physical conditions of the Glacial Period.[2]

We have seen that in the Caucasus the traces of former glaciation are more abundant on the northern than on the southern side of that chain—implying conditions which are quite analogous to those that obtain in our own day. We meet with a similar analogy between the present and the past in the Himalaya. It is in the exterior ranges of those mountains that the largest snow-fields and glaciers occur, and the same was the case in glacial times. At present the snow-fields and glaciers of the Himalaya increase in importance as the chain is followed from east to west and north-west, where in the Karakoram they attain their greatest development. And it is in precisely the same direction that the proofs of former extensive glaciation increase in

[1] *Manual of Geology of India*, Part II. pp. lxx. 374, 586–591; 2nd edit. (1893) p. 368.

[2] *Geographical Distribution of Animals*, vol. i. p. 150; *Island Life*, 2nd edit. p. 122.

importance. Obviously, in glacial times as now, the mountains facing the south and south-west caught the largest snowfall. Of the old glacial phenomena of Thibet we have little knowledge. They would appear not to be very conspicuous. The brothers Schlagintweit who traversed those elevated regions could find no trace of any general and extensive glaciation, and other observers, such as Dr. Stoliczka,[1] Colonel Godwin-Austen, and Mr. Drew, either make no mention of glacial phenomena or refer to these in such a manner as to lead to the belief that they cannot be on the same scale as those that are seen farther south at much lower elevations. It would seem probable, therefore, that the lofty Thibetan plateaux have not been covered with any general massive *mer de glace*. At the same time we must remember that in those regions rock-disintegration is always active, and that the finer and more convincing evidences of former glacial conditions, such as polished and striated surfaces, could not be expected to endure for any lengthened period. The 'roof of the world' has not yet been sufficiently explored to enable us to assert that in glacial times it must have been as dry and desiccated a region as it is at present. For many years it used to be confidently stated that no glaciers had existed in the Ural Mountains—but recent research has proved this to be erroneous; and it is not at all improbable that renewed investigation of the Thibetan plateaux may similarly cause us to modify our views as to the condition of those regions during the Glacial Period.

In the bordering mountain-ranges that flank the high plateaux on the north-west the traces of former glaciation are more or less well displayed. Thus we learn from N. Severtsof that conspicuous terminal moraines occur in the

[1] Stoliczka mentions the occurrence of great banks and sheets of gravel and débris, probably of 'diluvial' age, in the river-valleys of East Turkestan (on the borders of Kaschgar). Near Aktagh (15,590 ft.), on the northern slopes of the Karakoram, he met with stratified clays about 160 ft. thick, which covered an area of more than 100 square miles. These were obviously lacustrine, and he infers that at the time of their formation the climate of that elevated cold and dry region was milder and more humid than now. Further evidence in support of this conclusion is the occurrence in the clay deposits of that region of *Succineæ, Helices, Pupæ*. Land-molluscs could hardly exist in that region under present conditions. (*Petermanns Mitt., Ergänzungsheft* 52, p. 22.)

Thian Shan Mountains at a height of 2,500 ft. above the sea, indicating, according to him, a depression of the snow-line of 4,000 ft.[1] In like manner the valleys of the Altai are described by Bialoveski, Michaelis, and Sokoloff as having been occupied by glaciers. Indeed glaciers would appear to have existed in most of the alpine ranges that border the great plateaux in Eastern Siberia.[2] In the mountains south-west from Olekminsk Kropotkin discovered ground-moraines, terminal moraines, and erratic blocks, at a height of 1,700 ft., betokening the well-marked glaciation of a mountain-region which does not exceed 4,000 ft. to 4,600 ft. in elevation. The same geologist describes the Vitim Plateau south-east of Lake Baikal as plentifully besprinkled with lakes, and showing by the presence of glacial striæ and erratics that it was formerly covered by a continuous ice-sheet. Farther to the north-east the former occurrence of glaciers in the Stanovoi Mountains is evidenced by the appearance of erratics and morainic débris and numerous lakes, while traces of glacial action have been noted in the land of the Chukchis. In short, Kropotkin's researches have led him to conclude that 'the whole of the upper plateau of Asia and its border-ridges were under a mighty ice-cap.'[3] According to Przevalski, undoubted traces of former glaciation are seen in the Suma-Hada range, west of Kalgan in China, and similar evidence occurs in the high ground near the mouth of the Amur and amongst the mountains on the borders of Manchuria and Korea.[4]

These, as far as I can learn, are the only regions in Asia which have yielded certain traces of glaciation. (See Plate XIV.) Prince Kropotkin tells me, however, that snow-fields

[1] *Journ. Roy. Geograph. Soc.* vol. xl. p. 343; *Petermanns Mitt.*, *Ergänzungsheft*, No. 42, pp. 6, 20.

[2] The Sayan Mountains (11,000 ft.) are supposed to have been glaciated, striated blocks having been obtained at their base from the bed of the Yenessei; but according to Tscherski the markings are only 'pseudo-glacial,' and the result of weathering due to the peculiar structure of the stones. (See *Mém. de l'Acad. impér. des Sciences de St.-Pétersbourg*, 7[e] Sér. t. xl. No. 1, p. 25.)

[3] *Isviestija Imp. rosskoi Geogr. Obschestva*, Bd. iii. 1873; *Petermanns Geog. Mitt.*, 1867, p. 161; *Chambers' Encyclopædia*, p. 489. See also Severtsof's paper, *Congr. intern. des Sciences géogr. de Paris*, 1878, p. 248; and E. Brückner, *Neues Jahrb. für Min.* &c., 1885, Bd. i. p. 236 (Briefw.).

[4] *Finsk Tidskrift*, Bd. x. p. 208; cited by Nathorst, *Vega-Expeditionens Vetenskapliga Iakttagelser*, Bd. ii. 1882, p. 149.

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dur ... by the appearance of its old terraces at a height
... ft. above its present surface. Similarly, the old
... aces of Lake Baikal reach an elevation of not less than
... ft. above the present level of the water.[1] The Han-
... or great Dry Sea (about 2,000 ft. above sea-level), which
extends from Eastern Turkestan towards north-east for a
distance of 1,800 geographical miles, formed at the end of
the Cretaceous period a Mediterranean that communicated
with the Pacific Ocean. Bounded on both sides by lofty
mountain-ranges, this great depression has been for a long
time the receptacle of much sediment washed down by
streams and rivers. When, during Tertiary times, communi-

[1] *Petermanns Mitt., Ergänzungsheft*, No. 43, pp. 67, 102.

cation with the ocean was cut off, the Han-Hai became an inland sea, the waters of which have since been gradually evaporated—all that now remains being a few salt lakes. The process of desiccation, however, had not reached this stage in glacial times—all the evidence conspiring to show that the Han-Hai was then a much better watered region than it is now. In the low-grounds of Siberia we meet with similar proofs of former more humid conditions—lacustrine and fluvio-lacustrine deposits of Pleistocene age being well developed in many regions. From these have been obtained abundant remains of the Pleistocene mammalia, which are also well represented in the cave-deposits of the Altai and other places.

Immense sheets and terraces of löss fringe the alpine lands and sweep outwards upon the low-grounds of Turkestan and Siberia, but do not seem to go much farther north than 54° N. L. These, as Kropotkin shows, present the same character as the similar accumulations of Europe, and have yielded remains of mammoth, rhinoceros, &c., and land-shells. In Northern China the same accumulation is developed on a yet grander scale—covering enormous areas, and occurring at all altitudes from a few feet to upwards of 8,000 ft. above the sea. The distribution of the Asiatic löss, its general character, and the nature of its organic remains hardly allow us to doubt that it has been formed under the same conditions as the similar deposits in Europe. Its materials, we may believe, are largely of fluvio-glacial origin, and represent in great measure the flood-loams swept down from the mountains and plateaux when these supported extensive snow-fields and glaciers. But, as Baron Richthofen in his great work on China has demonstrated, the löss, as we now see it, owes its structure and heaping-up to the action of the wind, and is even now forming and accumulating in many regions of Asia. It is, in short, a true steppe-formation.

In the north-west of Siberia the appearance of clays, &c., with arctic shells shows that in Pleistocene times a great gulf of the sea extended southwards up the valley of the Yenessei as far at least as 67° N. L. This submergence does not seem to have affected East Siberia, for arctic shell-beds

have been met with only in a few places in that region. They have been recorded by Baron Toll and Dr. Bunge from the northern point of the island of New Siberia and by A. Krause from the coasts of Behring Strait. From the observations of Toll and Bunge it would seem that the Liakov Islands formed part of the mainland during the invasion of the Yenessei region by the Arctic Sea. Otherwise the north coasts of Eastern Siberia do not appear to have differed much from the present.[1]

When we attempt to determine the succession of events in Asia during Pleistocene times we find ourselves at a great disadvantage. In Europe the occurrence of interglacial deposits in the glaciated areas and the relation of fluvio-glacial deposits to fossiliferous river-gravels afford certain definite geological horizons, and make it possible to correlate the evidence over broad regions. But in Northern Asia we are without such aids. No interglacial deposits have yet been detected there, and the precise relation borne by the Pleistocene lacustrine and fluviatile deposits to the morainic accumulations of the mountains cannot be determined. According to M. Tscherski, however, the Pleistocene accumulations may be grouped as follows:—

I. LOWER SERIES, embracing the arctic shell-beds of the north; lacustrine and fluviatile deposits in the low-grounds; and glacial accumulations in the mountains.

II. UPPER SERIES, represented by the lacustrine and fluviatile deposits of North Siberia which overlie the arctic shell-beds and the 'ice-formations' of the Liakov Islands.[2]

M. Tscherski, therefore, is of opinion that the arctic shell-beds of the Yenessei are on the general horizon of the glacial deposits of Northern Europe. But, as we have seen, the

[1] Geologists have often speculated as to a connection in Pleistocene times of the Aralo-Caspian depression and the Arctic Ocean. Of such a connection, however, there is no geological evidence. The Caspian was certainly united with the Aral Sea, and much of the surrounding low-lying regions were then submerged (see Plate XIV.), but there is not the slightest evidence to show that the Caspian waters ever approached the watershed of the Obi. The occurrence of arctic forms of fish and crustaceans in the present Caspian Sea can be otherwise accounted for. See N. Andrussoff, *Izviestija Imp. rossk. Geograph. Obschestra*, 1888, Bd. xxiv.; Hj. Sjögren, *Jahrb. d. k. k. geol. Reichsanstalt*, 1890, Bd. xl., p. 51.

[2] *Mém. de l'Acad. imp. des Sciences de St.-Pétersbourg*, 7e Sér. t. xl. No. 1., p. 41.

glacial series of our Continent is highly complex, and the correlation of the Russian observer is therefore too vague. The shell-beds in question can hardly represent the whole glacial succession of Northern Europe, but must pertain to some particular stage of that series, and we shall probably not err if we assign them to the same horizon as the similar deposits of the Petschora Valley and the borders of the White Sea. Now in those last-named regions the marine beds are clearly younger than the ground-moraines. They are certainly of later date, therefore, than the epoch of maximum glaciation, and are in all probability on the same horizon as the Yoldia-clays of Sweden. The arctic shell-beds of Northern Siberia would thus pertain to a late glacial stage—to that, namely, which I have designated the fourth glacial epoch.

The shell-beds, as already indicated, are overlaid in Northern Siberia by fresh-water deposits containing mammalian remains, and in the Liakov Islands by the remarkable 'stone ice' with its superjacent fresh-water accumulations. In the low lands traversed by the Gyda (between the Gulf of Obi and the mouth of the Yenessei, in 70° 10′ N. L.) the fresh-water beds yielded the skeleton of a mammoth, with the hide still partially preserved.[1] From the same beds were obtained remains of dwarf birch, willows (*Salix glauca* and *S. herbacea*), and larch, under conditions that precluded the possibility of their having been drifted from the south. This is in keeping with Schmidt's discovery of a fir (*Abies obovata*) in an intercalated peat-bed near Norilsk. In the same high latitude (72° N. L.) Lopatin found in a similar peat-bed relics of coniferous trees, and a thick stem of *Alnaster fruticosa*, standing upright with roots attached. This was in a most exposed part of the tundra, where nowadays *Alnaster* grows no thicker than one's finger. From the same fresh-water series, in the region of the Gyda, Schmidt obtained *Helix Schrenckii*—a species which does not now range so far north. These and other similar observations lead to the conclusion, as Tscherski remarks, that during the formation of the fresh-water beds the climate of Northern Siberia was less extreme than at present—a forest vegetation extending north to the shores of the Arctic Sea.

[1] Mag. Fr. Schmidt, *Ibid.*, 1872, t. xviii. p. 28

To-day the northern limits of tree-growth are met with at 67° N. L. west of the Yenessei, and at 69½° to 70° N. L. east of that region. The same fresh-water beds, consisting of sand, loam, and occasional gravel, and not infrequently containing layers of ice, have been followed eastwards from the valley of the Chatanga to the shores of Behring Strait. From these beds remains of the mammoth, often in a wonderfully fine state of preservation, have been obtained from time to time. On the coast of Behring Strait the mammoth-bearing beds overlie marine clays, &c., with arctic shells.[1]

More striking still are the observations of Dr. Bunge and Baron Toll, who visited the New Siberian Islands at the instance of the Imperial Academy of St. Petersburg. On the steep coasts of Great Liakov Island, between 73° and 74° N. L., they found the fresh-water beds resting upon ice. This bottom-ice showed a thickness of 60 to upwards of 70 ft., and was transparent and greyish-green in colour. Its upper surface was very uneven, presenting irregular stump-like projections and ridges with intervening depressions, which were filled up with alternating layers of frozen loam and ice.[2] It is from these frozen loams that the well-preserved remains of the mammoth have been obtained. Above these lower layers come beds of loam and sand, here and there containing seams of peat and lines of drifted plants, and abundant mammalian remains. In places where the ice-bed is thin or wanting one sees deposits of loam and sand (twenty feet thick), charged with stems, twigs, and leaves of dwarf birch and willow, together with shells (*Cyclas* and *Valvata*) that do not range now so far north, but reach their limits some three or four degrees farther south.

If we take a general glance at the Pleistocene mammalian fauna of North Asia, we find evidence of secular migrations similar to those that have taken place in Europe. On the one hand certain northern forms had a more southerly range than is now the case; thus the Arctic fox and the torquated

[1] For references to the geological literature of this enormous region see Tscherski's memoir already cited.

[2] Dr. Bunge remarks that were the temperature of the soil to rise above the freezing-point for only a short time the island would soon cease to exist—the deposits, converted into liquid mud, would flow off in all directions into the sea, leaving only four hills of solid rock remaining.

lemming, which do not exist south of 57° N. L., formerly ranged into Southern Siberia (54° N. L.). On the other hand, many species, now restricted to Middle and Southern Siberia, have in Pleistocene times flourished in the highest latitudes of the Continent. There is no doubt whatever that these animals were really indigenous. Their remains are of such a character and occur under such conditions as to preclude the possibility of transport by river-action from more southern latitudes. Thus in the region that is bounded on the south-west, south, and south-east by the Verkoyansk Mountains—a region lying north of the Arctic Circle—numerous mammalian remains occur belonging to species which at present live between 10° and 15° farther south. This region—in which the winter temperature falls to 68° C. below zero[1]—was formerly inhabited by mammoth, woolly rhinoceros, and bison, by great herds of horses, by the wapiti, which does not now range north of 60° N. L., by the tiger, that reaches its northern limits in 55° N. L., and by the saiga, a characteristic form of the steppes of East Russia and South-west Siberia. Yet all these animals formerly lived as far north as 74° N. L., when those regions were forest-lands, prairies, and steppes.[2]

While most of the mammalian forms appearing in the Pleistocene deposits of Northern Asia occur also in the contemporaneous accumulations of Europe, there are certain European species which apparently never ranged into Asia—viz. *Hippopotamus*, *Elephas antiquus*, and *E. meridionalis*. Of the many thousands of elephant-teeth obtained in Siberia, all without exception belong to the mammoth. It is noteworthy, moreover, that the cave-hyæna, so common in Europe, has been met with only in the caves of the Altai. In those caves, according to Tscherski, none of the high northern forms occur, even the reindeer (which in our day

[1] In February 1892 the temperature of the air at Verkoyansk (lat. 67° 34′ N.) is said to have fallen to −94° 6′ Fahr.—the lowest temperature ever recorded anywhere on the surface of the earth.

[2] The following is the list of Pleistocene species brought from the island Bolskoi Liakov by Bunge and Toll:—tiger, wolf, arctic fox, glutton, polar bear, voles (two species), lemming, torquated lemming, mountain hare, bison (*B. priscus*), musk-sheep, reindeer, wapiti (*Cervus Canadensis*, var. *maral*), saiga, horse, woolly rhinoceros, mammoth. These species were represented by upwards of 2,000 bones, &c. See Tscherski's memoir, pp. 46, 459.

lives in the mountain-regions of Siberia) being absent.[1] The same author remarks that such forms as bison, saiga, rhinoceros, mammoth, and horse occur at all horizons of the Pleistocene deposits of Western Siberia. He has collected their remains, along with *Corbicula fluminalis*, in the system of the Obi up to 55° N. L.

Nowhere in Northern Asia are Pliocene deposits known to occur. All the superficial accumulations belong to Pleistocence and Recent times, and these, as we have seen, can only be roughly correlated with the corresponding formations in Europe. The marine shell-beds of the higher latitudes belong almost certainly to a late stage of the Glacial Period, and the overlying fresh-water deposits must be assigned to a still higher horizon. Tscherski, indeed, maintains that they are of postglacial age. The fluviatile and lacustrine beds of Middle and Southern Siberia, on the other hand, represent the whole Pleistocene period. When that vast region comes to be known in greater detail, it may be possible to differentiate between the various accumulations, but at present this cannot be done. Meanwhile, it is interesting to know that relics of Palæolithic Man have been found in the same deposits with remains of mammoth, woolly rhinoceros, horse, wapiti, &c.,[2] near Irkutsk. The relics consisted of rudely worked bones, coarse objects of burnt clay, one of which was pyramidal in form and 'holed' for the obvious purpose of being fixed to a shaft, while the point was worn and blunted as if from use. Another implement was an arrow-head, fashioned from a nodule of sphærosiderite—a large number of such nodules being found near by in the same bed, as if they had been brought together for the purpose of weapon-making. Tscherski would assign these relics to a very late stage of Palæolithic times—to the so-called

[1] Tscherski gives the following list of species from the Altai caves :—*Hyæna spelæa*, *Felis tigris*, *F. uncia*, *F. lynx*, *Ursus arctos*, *Canis corsac*, *Meles taxus*, *Cervus elaphus*, *C. giganteus*, *Alces palmatus*, *Bison priscus*, *Bos primigenius*, *Equus*, *Rhinoceros tichorhinus*, *Elephas primigenius*. The caves of Nishne Udinsk (a little north of 54° N. L.) have yielded a different fauna :—*Vesperugo borealis*, *Plecotus auritus*, *Sorex vulgaris*, *Cyon nishneudensis*, *Vulpes vulgaris*, *V. lagopus*, *Ursus arctos*, *Gulo borealis*, *Mustella zibellina*, *Spermophilus*, sp., *Arvicola Middendorffii* (?), *Lemmus obensis*, *Lagomys hyperboreus*, *Lepus variabilis*, *Rangifer tarandus*, *Antilope saiga*, *Capra*, sp., *Equus caballus*, *Rhinoceros tichorhinus*.

[2] *Archiv f. Anthropologie*, 1879, Bd. xi. p. 313.

Solutrian period, or even to the beginning of the Magdalenian period. Nowhere in Siberia have any finely worked objects in bone, such as harpoons, nor etchings and drawings similar to those of the French and Belgian caves, been discovered.

As the marine shelly clays of Northern Siberia can hardly be on any other horizon than those of the Petschora Valley, the coast-lands of the White Sea, and Scandinavia, we should expect that the succeeding 'fresh-water' deposits of Siberia should have the same tale to tell as the corresponding accumulations in Europe. In the latter, as we have seen, tundra-conditions were prevalent in our now temperate latitudes, during the coming and going of the last great Baltic glacier. By-and-by, as the climate bettered, a steppe-flora and fauna replaced their Arctic predecessors, just as these were in time gradually supplanted by forest-conditions, the steppe-forms retreating eastwards and north-eastwards into Russia and Siberia. Eventually a genial climate reigned over Europe—the forests extending into high latitudes from which they have since entirely disappeared. It can hardly be doubted that the climate of Siberia must have been contemporaneously affected. The movement of elevation which caused the Yoldia Sea to retreat from Scandinavia brought about a similar change in Northern Russia and Siberia—the coast-lands of which advanced farther into the Arctic Ocean. Severe climatic conditions continued, immense snow-drifts accumulating in the hollows and depressions of the land, and in course of time passing into solid ice. Baron Toll describes the ice-formation of the Liakov Islands as a 'dead glacier,' but there can be little doubt that it originated in the same way as the similar formations in Northern Alaska. It represents, in short, the congealed snow-drifts of a late glacial epoch, and probably accumulated at a time when tundra- and steppe-conditions prevailed in Central Europe. When those conditions began to pass away in Europe and to be succeeded by the genial forest-epoch, the rigorous arctic climate which had hitherto characterised Northern Siberia would likewise begin to give way. With each recurring summer the sheets of congealed snow would tend to disappear. Here and there, however, thawing

soils and subsoils would be set in motion, and, creeping and flowing over the surface of the 'ice-formations,' would cover these to a less or greater depth, and so protect them from the influence of the sun. Eventually a tundra-vegetation appeared, and thickets of birch and willow and pine spread northwards to the shores of the Arctic Ocean. Under these conditions the Arctic coast-lands were visited in summer by mammoths and rhinoceroses, and by herds of horses, bisons, and wapiti. Nor is it hard to understand how the bulkier quadrupeds might now and again become trapped in the treacherous bogs and subjacent muds that covered and concealed the 'ice-formations.' Their carcasses, as we have seen, occur in the frozen muds that occupy deep clefts and hollows in the ice—regular pit-falls, from which escape would often be difficult or impossible. Again, we can hardly doubt that in winter many animals must now and again have perished in blizzards, and become entombed in snow-drifts, some of which may have subsequently hardened into ice, under a protecting cover of sand or mud. Such accidents must frequently have happened in the wide valleys, and in course of time the bodies thus buried would now and again be disinterred by the rivers, and their disjecta membra become entombed in fluviatile sediment. Travellers in Siberia describe the bones as occurring here and there in enormous quantities. Dr. Bunge, for example, obtained from one spot in a bed of sand on the banks of the Adytscha no fewer than 200 bones, representing mammoth, rhinoceros, ox, musk-sheep, horse (very common), and deer. M. Tscherski also remarks on the astonishing numbers of bones which are seen in certain places on the banks of the Tunguska—the remains of as many as ten different species occurring in one very limited spot.

From the foregoing considerations it becomes obvious that the mammoth and woolly rhinoceros survived in Siberia to a later date than in Europe. They would seem to have lived in Southern Siberia throughout the whole Pleistocene period, from which region doubtless they originally invaded our Continent. But with the approach of our genial forest-epoch (penultimate interglacial stage) they gradually vanished from Europe, to linger for a long time in

Siberia before they finally died out. The penultimate interglacial epoch in Europe was followed, it will be remembered, by a partial relapse to glacial conditions, when small local glaciers descended here and there to the sea-level in Scotland, and the great forests of the preceding epoch disappeared from wide regions. This change affected so wide an area of our Continent, that we may well believe it influenced also the corresponding latitudes of Central and Northern Asia. The Arctic forests must have died out along the Siberian coastlands, and the northern range of the Pleistocene mammals would be restricted. Perhaps it was during this cold stage that the mammoth and woolly rhinoceros became extinct. At all events, these animals had vanished from the Asiatic fauna before the advent in Southern Siberia of Neolithic Man.

We may now glance for a moment at the evidences of former glacial action which have been observed in Africa. In the Great Atlas terminal moraines, 800 or 900 ft. in vertical height, have been observed by Sir J. Hooker and Messrs. Ball and Maw[1] at an elevation of 6,000 ft. They describe also the occurrence of a series of ridges and rolling hummocks, and masses of angular débris, 300 or 400 ft. in height, and some 3,000 ft. above the sea, which extend along the base of the great escarpment that rises abruptly from the wide plains or table-lands of Marocco. The mounds do not rest directly against the escarpment, but occur as 'isolated mounds 200 or 300 ft. in advance, sloping down towards the escarpment in one direction, and in the other rolling away in great wave-like ridges and undulating sheets, which terminate at a well-marked line of demarcation, just where the level portion of the plain commences.' Where the internal structure of those mounds was visible, the angular débris showed an arrangement in layers that sloped away from the escarpment toward the plain. The stones had evidently been derived from the escarpment, and Mr. Maw thought the mounds were 'the result of glaciers covering the escarpment, leaving on their recession the intermediate depression.' He makes no mention, however, of glaciated surfaces, or of ice-marked

[1] *Journal of a Tour in Marocco and the Great Atlas*, Appendix H. See also *Quart. Journ. Geol. Soc.* vol. xxviii. p. 85.

boulders, and it seems more likely that the mounds in question are a kind of 'rubble-drift'—possibly formed in much the same way as the coarse limestone-breccias of Gibraltar. If we suppose the face of the escarpment to have been cloaked with drifted snow, this would form an inclined surface upon which angular débris, under the influence of frost and thaw, might travel from the crest of the ridge to the low-grounds at its base.[1]

The later researches of Mr. Joseph Thomson[2] have confirmed the results obtained by Sir J. Hooker and his colleague as to the former existence of glaciers in the Atlas. He discovered not only lateral and terminal moraines and erratics, but striated stones and scratched and polished rock-surfaces, which had been preserved under a covering of morainic débris. Lastly, I may note that M. Ch. Grad records the occurrence of what he took to be moraines at the mouth of the gorge of El Kantara, on the southern side of the Atlas in Algeria.[3]

I am not aware that traces of glacial action have been observed in any other part of North Africa. We cannot doubt, however, that during the Glacial Period the climate of that region must have been markedly affected, and evidence of this is furnished by alluvial accumulations of Pleistocene age. These show that North Africa was formerly in possession of a more humid climate. Thus in Algeria accumulations of loam, sand, and gravel, of fluviatile origin, attain a great development on the low-grounds at the foot of the Atlas, and have yielded remains of buffalo (*Bubalus antiquus*), antelope (*A. Gaudryi*), aoudad (*Ovis tragelaphus*), hippopotamus, rhinoceros, and horse (apparently the Pliocene species *Equus Stenonis*). These deposits are believed to belong to an old stage of the Pleistocene period. Later deposits in the same region contain the shells

[1] Something like this is seen near the summit of Kilimanjaro. Dr. H. Meyer says:—'A peculiarity of the snow-fields on the steep slopes of Kibo was the piles of stones ranged along their lower margins, almost like a moraine. They had apparently fallen from the rocks above and slid downwards over the smooth surface of the snow. Later on we saw the same thing repeated on the tali of Mawenzi.' (*Across East African Glaciers*, 1891, p. 312.)

[2] *Travels in the Atlas and Southern Morocco*, 1889, pp. 210, 276,-279, 319, 326.

[3] *Bull. Soc. géol. de France*, 3e Sér. t. i. p. 87.

of existing species of molluscs, and here and there the remains of living vertebrate forms; but this mammalian fauna departs widely from that now occupying Algeria. Amongst the species are elephant (*E. Africanus*), buffalo (*B. antiquus*), hippopotamus, urus (a very large form), bubaline antelope, sheep, aoudad, camel, horse (closely related to *Equus Africanus*), and another form (*E. asinus Atlanticus*), which has certain analogies with the extinct *Hipparion gracile* of Tertiary times. Besides these are the remains of a rhinoceros, the teeth of which cannot be distinguished from those of the woolly rhinoceros.[1]

It used formerly to be maintained that the desert of the Sahara was occupied by the sea in Pleistocene times,[2] but later observations have shown this view to be unfounded —only a relatively small portion in the region of the Chotts having been submerged. Erwin von Bary, Lenz, Zittel, Walther, and others have shown that the desert-sand is not a sea-sand—that there is no evidence that those wastes have been occupied by the sea at so recent a date as the Pleistocene period. The only fossiliferous accumulations of that age are of fresh-water origin.[3] There is no reason to doubt that in Pleistocene times the land-area in North Africa was not less extensive than it is at present. Indeed, there are good grounds for believing that during some stage or stages of the period a land-connection obtained between Africa and Europe by way of Malta and Sicily. What are now deserts appear to have been then traversed by streams and rivers, the dried-up courses of which (Wâdies) are seen in many places. The frequent occurrence also of calcareous tufas speaks to the former great abundance and volume of springs. In one of these tufas in the oasis of Chargeh, on the borders of the Lybian Desert, Zittel found leaves of the oak (*Quercus ilex*), the presence of which, according to him, shows that the

[1] Ph. Thomas, *Comptes rendus hebdom. d. Séances de l'Acad. d. Sciences, Paris*, 1884, p. 381.

[2] Desor, *Aus Sahara und Atlas*, Wiesbaden, 1865; *La Forêt vierge et le Sahara*, Paris, 1879.

[3] E. von Bary, *Zeitschr. d. Ges. für Erdkunde*, Berlin, Bd. xii. p. 17; Lenz, *op. cit.* Bd. xvi. p. 291; Zittel, *Beiträge zur Geologie und Palæontologie der Libyschen Wüste*, &c., 1883, p. xxxvi.; Walther, *Die Denudation in der Wüste*, &c., 1891, pp. 139, 141, 185, 193.

tufa had been accumulated under more rainy conditions than now obtain. The tufa in question is ten to thirteen feet in thickness, more than 900 ft. in height, and three-fourths of a mile in length, extending along the flanks of a limestone plateau, over which the springs must have precipitated themselves for a long time.[1] In a word, it is the general opinion of those who have studied the desert-regions of North Africa that these were formerly better watered than now—traversed by streams and rivers, and diversified here and there by lakes, of which the numerous 'sebchas' and 'dayas' are the remains.[2]

The evidence of such a climatic change is not confined to North Africa. In Palestine and Syria similar proofs of former rainy conditions are forthcoming. Professor Hull has shown that everywhere the facts seem to point to a 'pluvial period,' which he thinks was most probably contemporaneous with the glacial conditions of Lebanon and Hermon. During this period the Jordan-Arabah depression was occupied by a lake more than 200 miles in length and 2,000 ft. in depth—the higher terraces occurring at a height of 1,300 to 1,400 ft. above the present level of the Dead Sea. To the same period, according to Hull, 'must be referred the erosion of the deep gorges and ravines of Palestine, and of the still wider valleys of Arabia-Petræa, which are seldom otherwise than dry beds of former rivers.' 'The magnificent valleys, with floors overspread by thick deposits of gravel, bounded by lofty escarpments of limestone, sandstone, or granite, like those of the Zelegah, the Feiran, Es Sheik, or El 'Ain, now almost waterless—all bear silent testimony to the same great physical change in the climate of the country.'[3] In short, there is no doubt that the border-lands of the Mediterranean were formerly well-watered—that they have experienced more humid conditions than now obtain. This is quite in keeping with what we have learned as to the former great abundance of lakes in Central and Northern

[1] *Beiträge zur Geologie und Palæontologie der Libyschen Wüste*, &c., 1883, p. cxli.

[2] An excellent summary of the evidence is given in Zittel's paper cited in preceding note. See also Professor Whitney, 'The Climatic Changes of Later Geological Times,' *Mem. Museum of Comp. Zoology*, Cambridge, Mass. vol. vii. No. 2, p. 144 *et seq.*

[3] *Survey of Western Palestine*, &c. pp. 79, 113–116.

Asia. All those regions are drier now than they were in Pleistocene times. More than this, it seems most probable that the humid conditions of the Mediterranean lands extended even into tropical Africa. This is shown by the presence of numerous dried-up river-courses and alluvial plains of great extent, as, for example, in the neighbourhood of Lake Tchad, which originally covered a much more extensive area.[1] No one, indeed, can study the many volumes of travel that deal with Central Africa without being impressed with the evidence that seems to suggest a former greater rainfall. Wide alluvial plains are described as sweeping out from the base of mountain-regions and presenting in their highly denuded aspects the evidence of considerable age. Such is the desert tract known as Shol, which extends from the base of the mountains of Abyssinia to the sea, north of Massowa. The southern portion of this plain has been so denuded by streams and surface-waters that it now consists of a series of low flat-topped hills.[2]

No traces of ancient glaciation have been recorded from the lofty plateaux and heights of Abyssinia. Dr. Gregory, however, describes the occurrence in British East Africa of moraines, striæ, glacial lake-basins, perched blocks, and *roches moutonnées* below the present limits of the glaciers of Mount Kenia (18,370 ft.), which is situated immediately south of the equator. He maintains that the evidence indicates 'the existence of a "calotte" or ice-cap, extending at least 5,400 ft. farther down the mountain than the termination of the present glaciers, and possibly farther, for in the belt of forest detailed observations could not be made.' This more extensive glaciation, he thinks, has been produced by a former greater elevation of Mount Kenia, and does not call for any theory of universal glaciation.[3] But Mount

[1] See Sig. E. Lombardini's paper, 'Tracce del periodo glaciale nell' Africa Centrale,' *Rendiconti dell' I. R. Ist. Lombardo di Scienze*, &c., 1866, vol. iii.; *Giorn. dell' Ing.-Arch. ed Agron.* vol. xiv.

[2] W. T. Blanford's *Geology and Zoology of Abyssinia*, p. 194.

[3] *Proc. Geol. Soc.*, No. 626, May 1894. In the short abstract of Dr. Gregory's paper no evidence is given as to the former greater elevation of Mount Kenia, apart from that supposed to be furnished by the glaciation. One would like to know what are 'the many facts in African geology' which are opposed to the view that the snow-line may have been depressed generally. A lowering of the temperature for a very few degrees, with increased precipitation, is probably all that would be required to bring back the old 'calotte' to Mount Kenia

Kenia is not the only glaciated mountain in East Africa. The extinct crater of Kilimanjaro (19,720 ft.) is occupied by ice, and glaciers appear in the deep ravines and gullies that come down from the crest of the cone. Dr. Meyer mentions that glacial markings are common on the rocks lining the sides of the ravines. In the great ravine, the upper reaches of which are occupied by the Ratzel glacier, he observed that the rocks far below the limits now reached by the ice were polished and scratched to a height of over thirty feet from the ground, the striæ running parallel to the course of the valley.[1]

In South Africa, again, Mr. G. W. Stow has detected traces of glaciation in the mountains of Kahlamba, &c., with elevations ranging from 1,000 ft. to upwards of 5,000 ft. The evidence consists of *roches moutonnées*, erratics, clays with boulders, and, in one place, ice-scratchings or groovings upon a rock-surface. He mentions also the discovery by Mr. Gilfillan of a large boulder distinctly striated, and of a gravel-bed in which almost every boulder was marked with striæ on one or more sides.[2]

Ten years ago Mr. J. Stirling[3] announced the discovery of glacial phenomena in the valley of the Mitta-Mitta, a tributary of the Murray, in New South Wales, but his observations do not appear to have attracted much attention. Somewhat later, however, Dr. von Lendenfeld reported the occurrence in the Australian Alps (lat. 37° S.) of *roches moutonnées* scattered over an area of about 100 square miles in extent, upon a plateau reaching an elevation of 5,800 ft.[4] He did not, however, detect any glacial striæ, and as crystalline rocks, such as those of Mount Kosciusko, not infrequently assume rounded forms under the influence of weathering, the evidence adduced by him was considered insufficient. The photo-

[1] *Across East African Glaciers*, p. 318.

[2] *Quart. Journ. Geol. Soc.* vol. xxvii. p. 534; vol. xxviii. p. 17. Some doubt has been cast upon Mr. Stow's conclusions by Dr. A. Schenck (*Verh. des VIII. deutschen Geographentages in Berlin*, 1891), who says the rounded rocks are not *roches moutonnées*, and that the sheets and heaps of so-called morainic débris, &c., are simply blocks rolled down from the adjacent mountain-slopes and mixed with loam—the result of weathering. According to him there is no evidence of any general glaciation. It is possible, therefore, that Mr. Stow has exaggerated the extent of the glaciation, and that at the most only small valley-glaciers formerly existed in South Africa.

[3] *Trans. Roy. Soc. Vict.*, 1884, p. 23.

[4] *Proc. Linn. Soc. N.S.W.*, 1885, p. 45.

graphs taken by Lendenfeld certainly suggested a glacial origin for the smoothed and rounded surfaces, and it is hardly likely that an observer familiar with the *roches moutonnées* of Switzerland could have misinterpreted the evidence. But to remove any doubts Dr. Lendenfeld, accompanied by Mr. Stirling, visited Mount Bogong (6,508 ft.), the highest mountain in Victoria, and succeeded in finding the clearest traces of glaciation, consisting of *roches moutonnées*, striated surfaces, perched blocks, and moraines. From his observations Lendenfeld concludes that the Australian Alps have certainly been occupied by glaciers, which descended to the level of 1,000 metres (3,281 ft.) above the sea.[1]

Professor Tate has likewise described the occurrence of glaciated surfaces at Hallet's Cove, south of Holdfast Bay, in St. Vincent Gulf, South Australia (lat. 35° S.). He traced them for a distance of several miles along the top of the scarped cliffs, at about forty feet above the sea-level. The glaciated surfaces are more or less continuous, but here and there they have been removed, owing to encroachment of the sea, which has cut back the cliffs. On the north side of Hallet's Cove 'the glaciated surface is beautifully displayed, the edges of nearly vertical strata are sheared off, and when of quartzite the surface shows a high polish, and when of mudstones conspicuous grooves and striæ.' Morainic débris is said to be very abundant in places, including many boulders, some of which occur as *blocs perchés*. The erratics consist principally of granites, gneiss, hornblende-schists, &c., which do not occur *in situ* nearer than the Gorge at Normanville, about forty-six miles to the south. Tate does not express any opinion as to the direction in which the ice moved, but he apparently inclines to the view that the glaciation is the result of local glacial action—that is, of ice coming from the Adelaide chain. The mountains, he suggests, may formerly have been much higher, say 10,000 ft.; or, they may have had a more plateau-like form (better fitted to collect snow), and need not therefore have been so high; or, without much if any change in the relative height of the land, the climate

[1] Lendenfeld, *Mining Registrar's Returns for Quarter ended March* 1886—*Mining Dep. Victoria; Australische Reise*, Innsbruck, 1892, p. 93; J. Stirling, *Proc. Linn. Soc. N.S.W.*, May 1866; *Nature*, vol. xxxv. p. 182.

may formerly have been very much colder. Either one or other of these conditions or a combination of all might have caused the glacial phenomena. Dr. von Lendenfeld, on the other hand, suggests that the rock-smoothing may have resulted from the stranding of icebergs coming from the Antarctic regions, and bringing with them erratics; while Mr. R. M. Johnston would attribute the phenomena to the 'grinding action of partly stranded sheets of the Antarctic drift-ice, whose extreme northerly limits, even in the present mild epoch, ascend almost into the same degree of south latitude in the vicinity of the Cape of Good Hope.'[1] Professor Hutton objects to the Antarctic origin of the erratics, because 'all the land that has been examined in that direction is volcanic.'[2] But specimens of granite, schistose, and old sedimentary rocks have in recent years been brought from the Antarctic, and the evidence collected by the 'Challenger' Expedition goes to show that such rocks must enter largely into the composition of the ice-drowned Antarctic lands. Dr. Murray remarks that 'in the Central Pacific, as the fortieth parallel of south latitude was approached, a few rounded fragments of granite and quartz were dredged from the bottom of the sea. The same occurred in the South Atlantic in high latitudes,' 'and as the "Challenger" proceeded towards the Antarctic Circle in the South Indian Ocean these fragments of continental rocks increased in number, till at the most southerly points reached, they, along with the mineral particles and muddy matter derived from the continental land, made up by far the larger part of the deposit. These fragments consisted of granites, quartziferous diorites, schistoid diorites, amphibolites, mica-schists, grained quartzites, sandstone, a few fragments of compact limestone, and partially decomposed earthy shales.'[3]

Professor Hutton's objection therefore no longer holds good. Mr. R. L. Jack, Government Geologist of Queensland, and formerly of the Geological Survey of Scotland, visited Hallett's Cove in 1891, in company with Professor Tate, and was able to satisfy himself that the latter's observation

[1] Tate, *Anniversary Address, Trans. Roy. Soc. S. Australia*, 1878-79; *Austr. Assoc. Adv. of Science, Proc.* 1890, vol. i. p. 231; Lendenfeld, *Proc. Linn. Soc. N.S.W.* vol. x. p. 45.

[2] *Proc. Linn. Soc. N.S.W.*, 1885, p. 335.

[3] *The Geographical Journal*, vol. iii. (1894) p. 11.

was correct in every particular. Mr. Jack's familiarity with glacial phenomena enabled him also to determine the direction of the ice-movement, which was from south to north, and he does not hesitate to express his firm belief that a sheet of ice has moved up St. Vincent Gulf in that direction.[1] My friend and former pupil, Mr. William Anderson (late of the Geological Survey of New South Wales), tells me that he also has seen the striated surfaces referred to, and has no doubt whatever of their glacial origin. The proximity of an escarpment of Tertiary rocks had suggested to Tate the possibility of the pre-Miocene age of the glaciation. But the conglomerate at the base of the Tertiaries contains only local materials, and he thought it highly probable that the glacier had cut its way through the incoherent Miocene beds. The restriction of the phenomena to the neighbourhood of the coast-line, and the absence of similar phenomena in the adjacent Adelaide Range, which does not average over 2,000 ft. in height, are rather suggestive. Had the smoothed rocks on the coast resulted from the action of local glaciers, convincing evidence of the former existence of these ought to be forthcoming in the hill-valleys, but have nowhere been observed. Prof. Tate does, indeed, refer to the occurrence of rounded surfaces of mica-slate on the southern flank of Kaiserstuhl, but these might have resulted from mere surface-weathering of the rock.[2] Even if we reject his interpretation of the evidence, and accept that suggested by Mr. Johnston, the conclusion that the Antarctic ice-pack formerly reached to South Australia is sufficiently startling, while Mr. Jack's suggestion that the South Polar ice-cap actually invaded the coast-lands of South Australia fairly takes one's breath away!

Australian geologists are generally agreed that the broad gravel-terraces and alluvial flats and plains in the main valleys and low-grounds of the Colonies indicate a former greater precipitation and much larger rivers than now exist. The accumulations reach occasionally the great thickness of 300 ft., and are variously assigned to the Upper Pliocene and Pleistocene periods. It is noteworthy that these deposits

[1] *Geology and Palæontology of Queensland and New Guinea*, p. 619.

[2] Striated rocks, however, are said to have been detected by Mr. Brown in the Mount Lofty group, near Adelaide, at a height of about 600 metres (1,968 ft.); Lendenfeld's *Australische Reise*.

not infrequently become very coarse, and now and again contain boulders, some of which may be two or three feet in diameter—and such rough gravels and shingle often occur at heights and in positions where it is hard to see how they could have resulted from ordinary river-action. As an example may be cited the occurrence of numerous large boulders in the course of the Murray River at its junction with the Campaspe[1]—boulders which must have travelled long distances, and which could not have been transported by ordinary river-action across the great plains—the slope of which does not exceed two feet in the mile. The fall of the Murray River from the mouth of the Mitta-Mitta to the Campaspe junction is said to be less than one foot. It is a question, therefore, whether the boulders may not have been carried by ice-rafts.

Within the past year (1893) several observers have described the occurrence of well-marked glaciation in the alpine valleys of Western Tasmania. Mr. R. M. Johnston tells us that the evidences of glacial action in that region were first detected some forty years ago by Mr. Gould, whose observations were subsequently confirmed by Mr. Sprent[2] and by Mr. Johnston himself.[3] The phenomena consist of striated surfaces, *roches moutonnées*, moraines and large erratics, and glacially eroded lake-basins. These earlier notices of Tasmanian glacial action have been abundantly corroborated by Messrs. E. J. Dunn, T. B. Moore, and A. Montgomery.[4]

It appears that the glaciers came down to the level of 2,000 ft. above the sea, and, so far as is yet known, they would seem to have been confined to the Western Highlands. But certain observations made by Mr. Moore would lead one to suspect that the glaciation was more extensive than might at first sight appear. It is in the mountain-valleys descending from the great central plateau of the island (4,000 to 5,000 ft. in height) that the glacial phenomena are so well-exposed. But Mr. Moore tells us that Mount Tyndall (3,870 ft.) is striated and polished up to within twenty-five feet of the

[1] Hodgkinson, *Trans. Roy. Soc. Vict.* vol. i.
[2] *Trans. Roy. Soc. Vict.* vols. iii.–iv.
[3] *Geology of Tasmania* (1888), pp. 164, 216, 219, 254–256, 296; *Proc. Roy. Soc. Tasmania*, June 1893.
[4] Dunn, *Evening Standard*, Vict., 1893; Moore, *Proc. Roy. Soc. Tasmania*, April 1893; Montgomery, *ibid.* May 1893.

summit. And it is evident, as Mr. Johnston remarks, that the snow lying above this level could not have sufficed to generate glaciers. He thinks it possible, therefore, that the great catchment basin of the central plateau was itself the source of the glaciers which streamed westwards, descending such valleys as those of the North and South Eldon. Whether any glaciers formerly existed in the Eastern Highlands remains to be determined. Mr. Johnston thinks it is improbable, and that the development of ice in the west of the island is in keeping with existing meteorological conditions —the mean annual rainfall in the west being 65·78, while that of the east is only 25·42. If a similar disparity obtained during the Glacial Period it is obvious that the glaciers of the Western Highlands must have considerably exceeded in size any that could have been maintained on the other side of the island.

As in Australia, so in Tasmania, coarse gravel and shingle in banks ('Esker Drifts') and in terraces ('Lower Terrace Drifts') are supposed to indicate the former prevalence of 'pluvial' conditions.[1]

The researches of Haast, Hector, Hochstetter, Hutton, Lendenfeld,[2] and others have familiarised us with the fact that the existing glaciers of New Zealand are the descendants, so to speak, of far greater ice-flows, which reached the plains on the east side of the island, and, in the west, may even have entered the sea, for erratics and moraines occur upon the coast, and appear to extend outwards under the sea. The greater development of glaciers in the west is quite in keeping with existing conditions. At present the snow-line is met with on the west side of the Alps at a height of 5,500 ft., while on the east it rises to 6,500 ft. Hence the western

[1] *Outline of the Geology, Fauna, and Flora of Tasmania*, by R. M. Johnston, 1892.

[2] The literature dealing with New Zealand glaciation is somewhat scattered, and I give only a few references:—Haast, *Quart. Journ. Geol. Soc.* vol. xxi. pp. 130, 133; vol. xxiii. p. 342; *Phil. Mag.* vol. xxix. pp. 159, 398; vol. xxxiv. p. 399; *Geology of Canterbury and Westland*; Hector, *Quart. Journ. Geol. Soc.* vol. xxi. p. 124; *Phil. Mag.* xxix. p. 157; *Geol. Mag.* vol. ii. (1865) p. 377; vol. vii. (1870) p. 95; *New Zealand Exhibition Jurors' Reports*, p. 263; *Trans. N.Z. Inst.* vol. ii. p. 372; *Anniv. Address, Wellington Phil. Soc.*, 1872; Hochstetter, *New Zealand*, 1867; Hutton, *Trans. N.Z. Inst.* vol. v. p. 384; *Geology of Otago*, p. 83; *New Zealand Journal of Science*, vol. ii. p. 266; *Proc. Roy. Soc. N.S.W.* 1885, p. 334; Lendenfeld, *Australische Reise*, 1892, pp. 174-191, 235.

glaciers descend some 1,600 ft. lower than those on the opposite side of the island—the former reaching the level of 700 ft. above the sea, while the latter terminate at a height of 2,400 ft. The positions occupied by the terminal moraines on the south-east side of the mountains show that the old glaciers were of very considerable importance.[1] Some of these moraines are 600 ft. in height, several miles in extent, and are met with at distances of 50 to 60 miles from the crest of the mountains. They are often piled up at the lower ends of long lakes, as Lakes Tekapo, Pukaki, and Ohau. It is notable that after these moraines were deposited, the glaciers appear to have retreated continuously, and perhaps somewhat rapidly, as no terminal moraines are again met with, except in the immediate neighbourhood of the existing ice-streams. While fresh-water lakes are well-developed in the valleys on the east side of the chain, just as is the case in Scotland, so, as in our own country, fiords put in a bold appearance in the west. There are thirteen of these sounds, of which the most northerly is Milford Sound—all apparently rock-basins. Thus Milford Sound is 1,180 ft. deep towards the middle, and 460 ft. deep at the entrance, while the depth of the sea outside is only 200 ft. Lendenfeld gives the average measurements and depths of all the New Zealand fiords as follows :—

Length	$15\frac{1}{2}$	miles.
Breadth	$1\frac{1}{4}$	mile.
Depth of the sea outside the entrance . . .	267	feet.
Depth at the entrance	328	"
Greatest depth about the middle	745	"

Now this greatest mean depth of 745 ft. is first met with in the outside ocean at a distance of nineteen to twenty miles from the coast, while the greatest depth of Milford Sound (1,180 ft.) is only attained again at a distance of 62 miles from land. All these fiords have undoubtedly been occupied by glaciers, as the ice-worn and polished rocks sufficiently show. In Milford Sound the ice-marks reach a height of 3,200 ft. at least—indicating for the old glacier a thickness of upwards

[1] Lendenfeld mentions the occurrence of glaciated rocks on the left flank of the Tasman Valley at a height of 700 metres (2,297 ft.) above the valley-bottom, thus indicating a thickness for the old Tasman glacier of about 2,300 ft. This glacier flowed for a distance of 56 miles; its existing representative is only nineteen miles long.

of 3,800 ft. The great depths met with in the New Zealand sounds are doubtless of the same origin as the similar depressions in the fiords or sea-lochs of North-west Europe. They are hollows ground out by glaciers. This has been clearly shown by Dr. von Lendenfeld, who remarks that the cross-section of each of the fiords has the U-shape, which is so characteristic of all mountain-valleys that have been occupied by glaciers. He points out, further, that the depths of the New Zealand sounds are in proportion to the size and character of the glaciers which formerly filled them. Thus Milford Sound is not so broad as the great sounds to the south of it; its old glacier, therefore, must have attained a greater thickness and flowed faster than the other glaciers. As a result of this greater thickness and velocity, it was enabled to grind out a deeper rock-basin than is found in any of the other fiords. To the suggestion that the diminishing depths of the fiords towards their entrances may have been caused by the accumulation of morainic materials, Lendenfeld replies that this is inconceivable. The distance from the watershed to the coast is only nineteen miles. The Milford glacier had thus a very narrow belt of land from which to obtain morainic materials. It is quite impossible, therefore, that it could have filled up the bed of the sea for a distance of 60 miles from the land with a mass of morainic accumulations having a thickness of 350 to 650 ft. In the south island of New Zealand, then, we find a close analogy to the conditions that obtain in Scandinavia and Scotland: on the west side of the watershed are great fiords, with deep hollows of glacial erosion, while on the east and south-east slopes are numerous lakes, each of which, as Hutton has shown, is similarly the result of ice-action.[1]

Professor Hutton and other New Zealand geologists are of opinion that the great development of glaciers in that

[1] *Trans. New Zealand Inst.* vol. v. (1872) p. 394. In this paper the author clearly demonstrates the absurdity of the notion that these rock-bound basins have resulted from movements of the crust. He says:—'In order to explain the formation of these lakes by unequal subsidence, and at the same time to account for other phenomena observed round the coast, we should have to imagine such a complicated system of local depressions and upheavals that they would more resemble the contortions produced by lateral pressure than any movements that we know, or have any right to assume, are going on at the surface of the earth.'

region took place at an epoch long anterior to the Glacial Period of Europe. This opinion is based partly on the fact that the marks of glaciation in the mountain-valleys and sounds of New Zealand are not nearly so well-preserved and fresh-looking as those in similar positions in Scotland and Norway. But the mountain-valleys and sea-lochs of North-west Europe were occupied by great glaciers at a very late stage of the Glacial Period. Hence the glaciation of those regions is much fresher than that which we see in the lowlands of Scotland for example. Again, the glacial markings in the upper valleys of the mountains of Middle Europe are altogether better preserved than those which occur at the lower levels. It is with these fainter and weather-worn *roches moutonnées*, &c., that the ice-markings on the flanks of the New Zealand sounds should be compared, and not with the fresh striated surfaces produced by the later glaciations. Professor Hutton is further of opinion, in opposition to Sir J. Haast and Dr. Hector, that the 'glacier epoch' of New Zealand occurred in early Pliocene times, while the latter are of opinion that it took place during the Pleistocene period. It is, of course, impossible to say whether the early Pliocene deposits of New Zealand are really contemporaneous with the 'older Pliocene' of Europe. But, as we have seen, glacial conditions supervened in Europe in late Pliocene times, and without committing oneself to the view that these conditions were contemporaneous in the two hemispheres, it may quite well be that the glaciers of New Zealand obtained a great development in the Pliocene period. Hutton supposes that this former great development was brought about by elevation of the land for 2,000 to 3,000 ft. He points out that neither in the Pliocene nor the Pleistocene deposits of the low grounds is there any evidence of a great general depression of temperature. The Miocene beds of New Zealand contain a series of fossils, the general facies of which is indicative of warmer seas than now lave those shores. No marine deposits of the Pliocene age are known, but beds of newer Pliocene and Pleistocene age occur, and their fauna, while showing that the waters were not so warm as in Miocene times, are of such a character as to preclude the possibility of any great diminution of temperature having

taken place. But, as Professor Hutton admits, it cannot be inferred from this that the great development of glaciers in New Zealand may not have been caused by a general reduction of temperature rather than by an elevation of the land. South of latitude 50° in Europe true glacial phenomena are confined to mountain-regions, and 'it is probable,' he adds, 'that if no land now existed north of that parallel of latitude the occurrence of a glacial epoch would never have been suspected.' This is putting the case more strongly than I would care to do, for the evidence suplied by the younger Pliocene and Pleistocene deposits in the coast-lands of the Mediterranean is certainly strongly suggestive of a reduced temperature.

Although I cannot find in the evidence adduced by New Zealand geologists any ground for believing that the islands during the 'glacier epoch' of that region stood 2,000 to 3,000 ft. higher than now, it is likely enough that they were then somewhat more elevated than now. Be that, however, as it may, there would seem to be no doubt that during some part of the Pleistocene period considerable depression took place, as is proved by the appearance of raised-beaches, and marine deposits up to several hundred feet above the present sea-level. It is notable, also, that in Pleistocene times the climate of the interior was more humid than at present—the now dry, treeless interior region of Otago being formerly covered with forest. Professor Hutton also cites the 'extraordinary agglomeration' of bones of the moa with remains of other species, which have been found mixed up with coarse gravel, as 'only to be accounted for by supposing that heavy floods swept these bones up, and deposited them in the low-ground.' Such facts, he thinks, indicate 'a diluvial epoch'—an epoch of 'greater winter snow-fall and greater summer floods.' [1]

Advancing now to a higher southern latitude, we reach Kerguelen's Land, most of the interior of which is covered with an ice-sheet and the glaciers that proceed from it. It was visited in 1874 by the 'Challenger' Expedition, and the observations then made showed that it had formerly been

[1] *Quart. Journ. Geol. Soc.* vol. xli. p. 213.

completely smothered in ice.[1] A somewhat similar tale is told of South Georgia, which supports several glaciers—one of them (Ross Glacier) is some eight miles in length. Old moraines show that its glaciers have been much larger, some valleys which are now free of ice exhibiting abundant traces of an earlier and more extensive glaciation.[2] The Falkland Islands do not appear to have been examined in detail by any competent geologist, but the general descriptions lead one to suspect that perennial snow and ice have formerly reigned in those regions. The greatest height reached is little over 2,300 ft., and the probabilities are that the islands were never capped by an ice-sheet, but there is evidence of the former action of severe frost and heavy snow-fall. I refer to the famous 'streams' or 'rivers of stones,' which are mentioned by every visitor to the islands. Darwin tells us that the blocks are not water-worn, and 'vary in size from one or two feet to ten or even twenty times as much. They are not thrown together into irregular piles, but are spread out into level sheets or great streams.' The thickness of these sheets is not known, but small streamlets can be heard trickling through the stones many feet below the surface. The width varies from a few hundred feet to a mile. The indication of the surface is very slight. On the hill-sides they slope at an angle of ten degrees, but in some of the flat-bottomed valleys the inclination is only just sufficient to be perceived.[3] These sheets of angular débris have in all cases travelled down the hill-slopes and valleys. In some places, according to Darwin, a continuous stream of rock-fragments could be followed up the course of a valley to the very crest of the hill, where huge masses seemed to stand arrested in their headlong course. The famous naturalist was puzzled to account for the phenomena, and suggested that the fragments might have been hurled down by earthquakes, and subsequently levelled into continuous sheets by 'a vibratory movement of overwhelming force.' But he was obviously hardly satisfied with this explanation, for he adds that 'the progress of knowledge will probably some day find a simple explanation of this phenomenon, as it already has of

[1] Moseley's *Notes by a Naturalist on the 'Challenger,'* p. 197.
[2] P. Vogel, *X. Jahresber. der geogr. Gesellsch. München für* 1885, p. 78.
[3] Darwin, *Naturalist's Voyage Round the World*, chap. ix.

the so-long thought inexplicable transportal of the erratic boulders which are strewed over the plains of Europe.' I do not think there can be much doubt that the 'stone-rivers' of the Falkland Islands are of the same nature and origin as the rubble-drifts already described in connection with the glacial phenomena of Europe. So far as one can judge from the accounts given of them by Darwin and Wyville Thomson,[1] they seem to be quite comparable to the limestone-breccias of Gibraltar, and the sheets of rock-rubbish known as 'head' and 'coombe rock' in England.

Roches moutonnées, striated rock-surfaces, erratics, and boulder-clays are met with over a wide region in the extreme south of Patagonia. Indeed, the researches of Darwin and Agassiz have shown that Patagonia has been sheeted in ice, the glacial phenomena being conspicuous over the whole region to the south of lat. 37° S.[2] North of that latitude the glaciers did not reach the sea, but great ice-streams appear to have occupied all the valleys of the Chilian Andes, as far north at least as Aconcagua. Traces of former extensive glaciation occur also in the neighbourhood of Lake Titicaca, in the Andes of Bolivia (Illimani, 21,000 ft.), and similar phenomena are encountered in the deep valleys coming down from El Altar (16,700 ft.), two degrees south of the Equator. Farther north still, in the mountains of Columbia, at Cocui (9,000 ft.), and in the Sierra Nevada de Santa Marta (15,400 ft.), the evidences of former glacial action are conspicuous. These, so far as I know, are all the occurrences of glacial phenomena which have been observed in South America. The traces of ice-action which Agassiz and Hartt supposed they had found in Brazil have been otherwise explained. Their *roches moutonnées* prove to be merely the weathered surfaces of exfoliating gneiss, &c., while their boulders and morainic débris are likewise the result of the weathering of rocks *in situ*. Indeed, both geologists had abandoned their former views on the subject for some time before they died.[3]

[1] *Nature*, vol. xv. p. 359; J. Geikie, *ibid.*, p. 397.

[2] Darwin, *Trans. Geol. Soc.*, 2nd Ser. vol. vi. p. 415; Agassiz, *Amer. Journ. of Science*, vol. iv. p. 135.

[3] See Professor Branner's paper, 'The Supposed Glaciation of Brazil,' *Journal of Geology*, vol. i. p. 753.

CHAPTER XLI.

GLACIAL PHENOMENA OF NORTH AMERICA.

By Professor T. C. Chamberlin.

Extent of glaciation—Laurentide glacier—Ice-movements; centres of dispersion—Enclosed driftless areas—Cordilleran glacier—Inland ice of Greenland—Imbrication of the drift series—Constituents of drift-deposits—The till—Drumlins—Åsar or eskers—Kames—Pitted plains or sand plains—Glacio-fluvial aprons and valley-drifts—Löss.

NEARLY one-half of the area of North America is covered with drift-deposits.[1] According to the majority of geologists this signifies that a tract of about 4,000,000 square miles has been overspread by glaciers in the Ice Age. Some eminent American geologists, however, dissent from this interpretation, and attribute the drift material of about one-half of this area to glaciers, and the other half to sea-borne ice. Sir William Dawson and Dr. G. M. Dawson, in particular, while holding that a great confluent glacier occupied the Laurentide uplands, that another covered the interior plateau of the northern Cordilleras, and that local glaciers gathered on the heights of the more southerly Cordilleras and the northern Appalachians, entertain the view that the remainder of the great tract was submerged and overstrewn with erratics through the agency of floating ice.[2] This view has the merit of a certain symmetry, and attracts one by its almost impartial recognition of the great agencies of land-ice and sea-ice; nevertheless, the uncompromising nature of the evidence presented by the deposits themselves, and by the

[1] [It is perhaps unnecessary to remark that the terms 'drift' and 'drift-deposits' are employed by Professor Chamberlin, in the same sense as 'diluvium,' to include all the accumulations of the Ice Age, as well glacial as fluvio-glacial, &c.—J. G.]

[2] *Trans. Roy. Soc. Canada*, vol. viii. sect. iv. 1890, pp. 25-74; *The Canadian Ice Age*, 1893, pp. 27-80. Map, p. 77.

PLATE XIV

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Stanford's Geog.l Estab.t

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ice-grooved rock-floor on which these rest, seems to compel the acceptance of the unqualified, or at least hardly qualified, glacial theory. With this recognition of the opposing view, the language of land glaciation will, in the following pages, be employed without reserve, not from any wish to dogmatise, but simply for the sake of brevity and clearness.

Under this interpretation, a bird's-eye view of the glaciation of North America would have presented, as its one dominating feature, a *mer de glace* spreading over the eastern five-sixths of the great Dominion of Canada, and enveloping the larger part of sixteen of the northern States of the Union and smaller portions of seven others—a vast sheet of ice, more than 3,000,000 square miles in extent. For this we find no better name than that proposed by Dr. Dawson—the Laurentide glacier. About four-fifths of the glaciated tracts of North America, measured by area, were occupied by this master glacier. Measured by mass, the predominance of the ice-sheet would doubtless appear even greater. Measured by southerly extension, it was still more extraordinary, for its apex was nearer the equator than the pole. This mightiest of glaciers was flanked on the north-east by the ice-field of Greenland, and on the north-west by the Cordilleran aggregation of glaciers. Both of these occupied mountainous tracts, while the great Laurentide ice-field was confined almost exclusively to plains or low plateaus. The inland ice of Greenland may possibly have been confluent with the Laurentide *mer de glace*, but the evidence at present seems, on the whole, strongly against this view. The Cordilleran ice-fields were clearly distinct from the Laurentide glacier.[1] It is not even known that their extreme margins ever touched, although this was probably the case in the far north.

The Cordilleran ice-fields, according to Dawson, were confluent as far south as the boundary between Canada and the United States, and large tongues protruded for short distances into Montana, Idaho, and Washington. South of this, the higher peaks of the Coast and Sierra Nevada ranges were strongly glaciated as far south as latitude 36° 40′, the

[1] G. M. Dawson, *Amer. Geologist*, Sept. 1890, p. 162.

ice descending the slopes in some instances down to within 2,000 feet of what is now the sea-level.[1]

Along the Rocky Mountain range notable local glaciation occurred as far south as latitude 37° 30′. Among the more important glaciers were those of the San Juan region, in south-western Colorado, those of the high ranges of central Colorado, of the Wind River mountains of Wyoming, of the Yellowstone Park, and of the Flathead region of Montana. Many small glaciers gathered in favourable localities along the range at intermediate points.[2]

Between the Rocky Mountains and the Coast ranges were a few local glaciers, the most important of which was that of the Uinta. Smaller glaciers accumulated on the Wasatch Mountains, on the Humboldt and West Humboldt ranges, the Shoshone range, the Granite range, the Springs range, the Powell Mountains, and probably at other points. There is little doubt that many small isolated glaciers likewise appeared in the intermediate ranges near the border of the northern confluent glacier, but these yet await definite mapping.[3]

It has been the opinion of several writers that local glaciation occurred along the Appalachian tract south of the main *mer de glace*; but as yet this has not been demonstrated, and the question of such local glaciation may be regarded as yet an open one.

Singularly enough, the north-western corner of the Continent appears to have remained essentially non-glaciated.

[1] J. D. Whitney, 'The Climatic Changes of Later Geological Times,' *Me[m.] Mus. Comp. Zool., Harvard College*, vol. vii. No. 2, 1880; I. C. Russ[ell], 'Existing Glaciers of the United States,' *Fifth Ann. Rept. U.S. Geol. Surv.* 1883-4, pp. 309-355; Clarence King, *U.S. Geological Exploration of [the] 40th Parallel*, 1878, vol. i. 'Systematic Geol.' pp. 459-531; J. S. Newb[erry], *Pacific Railway Exploration and Survey*, 1855, p. 41; *Colorado Explo[ring] Expedition*, 1857-8, pp. 22-49; Arnold Hague, *Geology of the Eureka D[is]trict, Nevada*, pp. 31-3; Joseph Le Conte, 'On some Ancient Glaciers of [the] Sierras,' *Amer. Journ. Sci.* vol. v. 1873, pp. 323-342.

[2] G. H. Stone, 'The Las Animas Glacier,' *Journ. Geol.* vol. i. (1893), 471-5; F. V. Hayden, *U.S. Geol. and Geog. Surv. Colorado*, 1878, pp. 51; W. H. Holmes, Hayden's *U.S. Geol. and Geog. Surv. Twelfth Ann. Rept.*; Arnold Hague, *Survey of the 40th Parallel*, 1878, 'Descriptive Geology,' pp. 96-7, 131; T. C. Chamberlin, *Seventh Ann. Rep. U.S. Geol. Surv.* 18[..] p. 78; G. E. Culver, *Trans. Wis. Acad. Sci.* vol. viii. (1892), pp. 187-205.

[3] G. K. Gilbert, *U.S. Geographical Surveys west of the 100th Meridian*, iii., 'Geology,' 1875, pp. 86-104; Clarence King, *Loc. cit.*; T. C. Chamberlin, *Loc. cit.*; Bailey Willis, *Bull. U.S. Geol. Surv.* 1887, pp. 1-10.

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According to the concurrent testimony of Messrs. Dall, Dawson, McConnell, Russell, and Hayes, the great plains of Alaska show no signs of general ice invasion. The interesting phenomenon of beds of ice buried beneath earth, sand, gravel, soil, &c., occurs at numerous points on the Alaskan coast north of Behring Strait, and at a few interior points, but these buried beds of ice do not appear to be the remnants of ancient glaciers.[1]

This rapid sketch may serve as a synoptical view of the glaciation of North America. From it let us turn back to the chief glacier.

The Laurentide Glacier.—The great north-eastern ice-sheet reached its southernmost extension in the State of Illinois, where a lobe stretched out on the plains between the Ohio and the Mississippi rivers to within 40 miles of their junction, attaining the very low latitude of 37° 35′. From this apex of glaciation—this supreme triumph of the ice—the limit of the invasion may be traced east-north-eastward in a sinuous course along the right-hand slope of the Ohio valley, swaying northward and southward through a considerable amplitude. In Indiana the drift border, as we now find it, retires well toward the heart of the State, but swings quickly back to the Ohio, and, crossing it, encroaches a little upon Kentucky near Cincinnati. It soon again strikes half-way back to Lake Erie, and thence runs easterly to the Pennsylvania line, where its course is north-eastward to western New York. Here, at a point about 33 miles due south from the foot of Lake Erie, the border-line trends away in a south-easterly course and runs with somewhat remarkable directness across the Appalachian range, reaching the Atlantic at New York Harbour.[2]

The angle in western New York has a latitude of about 42° 15′, from which it appears that, in passing eastward from Illinois to that point, the ice-border retired a little

[1] See *ante*, p. 664.

[2] A. H. Worthen, *Geology of Illinois*, vol. vi. (1875), p. 113; George Sutton, *Proc. Amer. Assoc. Adv. Science*, 1876, pp. 225–31; G. H. Cook and J. C. Smock, *Geol. Surv. of New Jersey*, vol. i. p. 116; *Ann. Rept. State Geologist of New Jersey*, 1887, pp. 9 *et seq.*; H. C. Lewis and G. F. Wright, *Penn. Geol. Surv.* 1884, *Rept.* 2; G. F. Wright, *Amer. Journ. Sci.* July 1883; *Trans. Western Hist. Soc.* 1884; *Bull. U.S. Geol. Surv.* 1890; R. D. Salisbury, *Geol. Surv. of New Jersey, Report of Progress*, 1892, pp. 60–79.

more than 4° 30′. In passing from the angle to the coast, it advanced to about 40° 30′ N. Lat., but still lacked nearly 3° of the phenomenally low latitude reached in the Mississippi Valley.

From New York Harbour eastward, the apparent limit (the proximity of the ocean rendering absolute determination impossible) follows the axis of Long Island and the coast islands as far as Nantucket, beyond which its further course is conjectural.[1] The ice edge, however, probably turned well to the north, and swept round the Bay of Maine, not far from the present coast, and entered the Bay of Fundy. According to Mr. Chalmers, the glaciation of the maritime provinces was essentially local, but that portion which occupied the highlands of New Brunswick may be regarded as essentially confluent with the ice of New England. Under this interpretation, the border-line may be carried onward along the axis of the Bay of Fundy and eastward so as to embrace Prince Edward Island, beyond which it probably swung round somewhat abruptly to the north-west (for the Magdalen Islands are not glaciated), and ran approximately parallel to the coast northward to the mouth of the St. Lawrence; where it perhaps incurved and formed a deep re-entrant angle, giving to the lower part of the St. Lawrence channel the character of an open fjord. This, however, is highly conjectural. It is supported by the statement of Mr. Chalmers that the ice-movement on the north slope of the Notre Dame and Green Mountains was northward, and even north-westward toward the St. Lawrence. He finds no evidence of southerly striation nor of the transportation of erratics from the Labrador highlands across this part of the valley.

Outside this border-line there was, according to Sir W. Dawson and Messrs. Chalmers and Murray, local glaciation in Nova Scotia, on the Cape Breton Islands, and in Newfoundland.[2]

[1] N. S. Shaler, *Illustrations of the Earth's Surface, Glaciers*, 1881, p. 42; *Seventh Ann. Rept. U.S. Geol. Surv.* pp. 309 *et seq.*; ***Ninth Ann. Rept.*** *U.S. Geol. Surv.* p. 546 *et seq.*; *Bull. U.S. Geol. Surv.* pp. 53; E. Hitchcock, *Surface Geology*, p. 32; Warren Upham, *Amer. Journ. Sci.*, Jan. 1891, p. 34.

[2] Sir J. W. Dawson, *The Canadian Ice Age*, 1893, pp. 151–195; Robert Chalmers, *Canadian Record of Science*, April 1889; *Rept. Geol. Surv. Can.*, 1885, and following years, and personal correspondence; A. Murray, *Geology of Newfoundland.*

Returning to the southernmost point of invasion in southern Illinois, and tracing the border-line in the opposite direction, this is found to be nearly coincident with the Mississippi as far north-west as St. Louis. From this point it turns westerly and runs near the Missouri river, as far as its northward bend at the Kansas line,[1] whence it keeps on westward for about 100 miles, and then curves abruptly to the right and pursues a north-north-westerly course until it again strikes the Missouri river near the mouth of the Niobrara on the southern line of South Dakota.[2] Thence onward its course lies close to the Missouri river to about the latitude of Bismarck (47°), where it turns westerly and keeps south of the Missouri river across the plains of Montana[3] to a point a few miles above the Great Falls of Missouri, where it crosses that river and turns to the northward, being now within about 40 miles of the Rocky Mountains. Its course is now northward, roughly parallel, so far as known, to the eastern base of the Rocky Mountains all the way to the mouth of the Mackenzie river. Across the vast north-western territory of the Dominion the limit has not been traced in detail, but the general fact that the 'eastern drift' stops short of the Rocky Mountains by distances usually ranging from 20 to 100 miles, seems well sustained by the reconnaissances of Messrs. Dawson,[4] Tyrrell, and McConnell. The border-line given on the map (Plate XIV.) is from Dr. Dawson's report. So far as is known, the Laurentide drift does not fully reach the Rocky Mountains proper along this border, though scattered erratics are found as far west as the foothills. In the lower Mackenzie Valley, according to Mr. McConnell, some of the outlying minor ranges of the Rockies are enveloped by eastern drift.

(Respecting the northern border of the great Laurentide glacier, information is very scant and not always capable of

[1] Scattered pebbly drift is reported by some of the Missouri and Kansas geologists as far south as Osage River, in Missouri, and 38° N. Lat. in Kansas (G. C. Swallow, *Geology of Missouri, first and second Ann. Repts.* 1885, p. 77).

[2] J. E. Todd, Correspondence.

[3] It has been reconnoitred, but not traced continuously, across this tract, and this statement is subject to a possible, but not probable, error (*Seventh Ann. U.S. Geol. Surv.* 1895–6, pp. 76–8).

[4] G. M. Dawson, *Geol. Surv. Can.* 1888; *Trans. Roy. Soc. Can.* vol. viii.; sec. iv. 1890, pp. 25–74; J. B. Tyrrell, *Geol. Surv. Can.* 1890, E. 1–240; R. G. McConnell, *Geol. Surv. Can.* 1888, D. pp. 24–8.

certain interpretation, but such as exists makes it probable that essentially all the mainland and the Arctic Islands in whole or in part were covered by ice.) Whether the ice on the islands was confluent with that of the mainland is not known, but a northward movement from the latter covering some or all of the former seems probable.

The eastern border is likewise undetermined, but perhaps coincided approximately with the present coast-line, when allowance is made for some probable encroachment upon the sea. It seems probable, also, that the border followed approximately the coastal line into the Gulf of St. Lawrence, and united with the border-line previously sketched, for the glaciation of Newfoundland appears to have been local, and, as already remarked, the Magdalen Islands in the midst of the Gulf of St. Lawrence are not glaciated.[1]

Ice Movements; Centres of Dispersion.—Taking a general view of the great area thus encompassed, it is worth observing that its centre is a broad low plain now below the sea-level—the bed of Hudson Bay. On the whole, therefore, the area is rather a basin than an embossment. The ancient *mer de glace* centred upon the broadest and lowest basin of the Continent. This lends peculiar interest to the evidences of glacial movement, and particularly to these as they bear upon the centre or centres of glacial origin, growth, and radiation. If the ice-tracks which are left to us represented the whole history of the movement, it would only need some few further observations in the north to determine the place of origin and the manner of dispersion. But doubtless most of the ice-groovings in the heart of the region represent little more than the last work of glaciation, and the ice, in its vanishing stages, may not have represented, in reverse, its method of growth. Much latitude for doubt, therefore, is left.

The ice-scorings and groovings near the margin of the area are almost invariably pointed directly toward the border. Even where the outline is highly lobate the law holds good. The striæ turn out toward the sides of the lobes to such an extent as to diverge widely from each other

[1] Sir J. W. Dawson, *Ice Age in Canada*, p. 154; Dr. A. S. Packard, *Boston Soc. Nat. Hist.* 1867.

and from the general direction of ice-movement.[1] All this, however, is merely a marginal phenomenon, dependent mainly on the local agencies that controlled the arrest of the ice-advance.

Passing by this and extending our view to a broader submarginal zone, from 300 to 500 miles wide, we find that, in the Eastern States, the general movement was south-easterly. This has usually been interpreted as a part of a general movement originating on the Laurentian highlands; but, according to Mr. Chalmers, the ice moved northward toward the St. Lawrence Valley, and even north-westerly from the mountains on the northern border of New England; and he is of the opinion that this represented the only movement of the region, the glaciation of New England being essentially local. In the eastern provinces, according to the official geologists of that region, the ice radiated from several centres of accumulation, as previously indicated. In the St. Lawrence Valley, above Montreal, the groovings indicate a movement south-westerly *up* the valley. This did not affect the more elevated borders of the St. Lawrence basin, and has usually been interpreted as a late movement or as an under-current controlled by the valley itself.

In the Mississippi basin the general movement was southward, but there was a notable tendency to convergence toward the axis of the valley. A complex south-easterly current set in from the Huron and Erie regions, a broad south-easterly current flowed in from the Red River basin of Manitoba and Minnesota, while a central stream followed the south-trending trough of Lake Michigan. The strangest feature of all is that, in the midst of these converging currents, and wrapped about by them, there lay a non-glaciated area of 10,000 square miles in the very axis of the Mississippi Valley, and traversed by the river itself. (See Plate XV.)

On the plains of Assiniboia, Saskatchewan, and Alberta, recorded striæ are few, but the drift-movement was clearly toward the south-west; probably more southerly than westerly, as urged by Mr. Tyrrell.[2] In the Upper Mackenzie

[1] See particularly the Green Bay Lobe, *Third Ann. Rept. U.S. Geol. Surv.* p. 316. See also 'Scorings of the Great Ice Invasions,' *Seventh Ann. Rept. U.S. Geol. Surv.* 1885-6, pp. 201-2.

[2] J. B. Tyrrell, *Bull. Geol. Soc. Amer.* 1890, p. 216 E.

basin, the movement, so far as determined, was westerly and, in the lower part of the basin, north-westerly.[1] Of the Arctic border not enough is known to justify a general statement, save that erratics on some of the islands seem to have come from the mainland to the southward.[2] In Hudson Strait the ice moved easterly, according to Dr. Bell, and in the Ungava basin northward. On the coastal zone of Labrador the movement was easterly so far as known, though Dr. Bell states that the highest points in eastern Labrador show no signs of glaciation.[3] In southern Labrador and eastern Quebec the direction was south-easterly and southerly toward the lower St. Lawrence basin.

Drawing more to the centre of the glaciated tract, it appears that, from the central highlands of Labrador there was a movement south-easterly, easterly, northerly, and westerly, seeming to make it clear that here was at least one centre of radiation—certainly so during the closing stages of the ice-period, and presumably so at all times during its history. This has been regarded by many as the original and chief centre of dispersion. There are many reasons, however, for questioning this. Its position is very far to the eastward of the centre of the glaciated area—indeed, it is in an angle, as it were. The apparently slight intrusion of the ice upon the Gulf of St. Lawrence, so close at hand, so near the ocean, and so high in latitude, seems strangely out of harmony with this view when note is taken of the vast extension of the ice westward, and even north-westward, as well as its great protrusion southward in the Mississippi Valley. The apex in the latter region was 1,500 miles away, and was 12° lower in latitude than the ice-border in the Gulf of St. Lawrence, which lay at the foot of the Labrador highlands, and not more than a fifth as far distant. In support of this view, however, is the fact that striæ and transported erratics show a descent from the Labrador plateau westerly and south-westerly into the southern portion of the Hudson and James Bay basin, and an ascent from it in a southerly and south-westerly direction.

[1] R. G. McConnell, *Ann. Rept. Can. Geol. Surv.*, 1888–9, D. pp. 26–7.
[2] For an excellent collation of the scattered data see *Ann. Rept. Geol. Surv. Canada*, vol. ii. 1886, pp. 56–8 R., by G. M. Dawson.
[3] Robert Bell, *Geol. Surv. Can.* 1882–4, D.D. pp. 36–7.

It has heretofore been supposed that there was an ascent westward also, but Mr. Tyrrell has recently found that the ice-grooves on the north-western shore of Hudson Bay from Chesterfield Inlet to Fort Churchill point south-eastward *into* the basin of the bay. Along Chesterfield Inlet they point southerly and south-easterly. At the head of the inlet the direction is reversed and the movement was north-westward. From the head of the inlet south-westward to the head of Athabasca Lake, along Mr. Tyrrell's route, the movement was found to be first north-north-westerly, then westerly, then south-westerly. South-eastward from the head of Athabasca Lake to the Churchill River the courses were found to be southerly and south-south-westerly. These courses, taken together with the collateral evidence of transportation, seem fully to warrant Mr. Tyrrell's belief that here was a second centre of dispersion, at least in the later stages of glaciation.[1] The striæ that point southward across Chesterfield Inlet are later than those near its head that point north-westward. This suggests a gathering area between the inlet and the Arctic sea at a late stage of glaciation, and may represent a corresponding gathering tract in an early stage of glaciation. The right flank of the ice-invasion may have come down on the west side of Hudson Bay, while the left took its start from Labrador. The eastward movement through Hudson Straits, determined by Dr. Bell, seems in harmony with these views.

Perhaps the most plausible hypothesis at present is that glaciation on the American mainland set in independently in Labrador and in the region north-west of Hudson Bay, perhaps in more than one locality, and that these nuclei grew until their borders coalesced, submerging the Hudson Bay region, and at length developing a great arcuate zone of accumulation along the Laurentian uplands from the coast of Labrador all the way round to the Arctic ocean, embracing at the maximum of glaciation a great reservoir of ice, as Dr. Bell has expressed it, in the Hudson basin. It is possible that the ice over this central basin grew to be a central embossment, but there is no evidence that it was ever so

[1] Personal Correspondence. Compare R. G. McConnell, *Ann. Rept. Geol. Surv. Can.* 1890-1, D. p. 62.

dominant as to cause the ice to push eastward over the Labrador plateau. An arcuate zone of accumulation, in a more restricted sense, has been a favourite conception of some American glacialists; but it is doubtful whether it could have originated as such, and the conception cannot be pushed very far in view of the abundant evidence of transportation from Hudson Bay south-south-westerly across the Laurentian tract, but not in the opposite direction. There seems no present ground for believing that the Laurentian uplands between Hudson Bay and Lake Superior were ever gathering grounds of such dominance as to produce a northerly movement of the ice.

Enclosed Driftless Areas.—Reference has already been made to the fact that the converging ice-streams of the upper Mississippi Valley wrapped about, but did not cover, an area in the north-central portion of the valley. The remarkable nature of this merits an additional word. It consists of a tract of about 10,000 square miles, lying chiefly in south-western Wisconsin, but embracing parts of south-eastern Minnesota, north-eastern Iowa, and north-western Illinois. It lies well within the extreme border of glaciation, there being 250 miles of drift between it and the nearest outer border. Its form and relations may be best seen by consulting the map. It did not owe its exemption from ice-invasion to altitude, for it is rather lower than adjacent glaciated tracts. The main drainage artery of the region lies directly across it, and is joined within its borders by two of its largest upper tributaries. The glacial streams, advancing from north and north-east, appear to have been diverted and retarded by the highlands north of the driftless region, while at the same time the great valleys adjacent led the currents away to the right and left so effectually that they were only reunited at some distance to the south. The portion of the ice-stream that succeeded in passing over the highlands was, as a result, relatively thin, and its movement sluggish, and thus it was consumed by melting before it completely overwhelmed the region lying in the lee of the highlands.[1] The driftless area

[1] N. H. Winchell, *Ann. Rept. Minn. Geol. Surv.* 1876, pp. 35–8; R. D. Irving, *Geology of Wisconsin*, vol. ii. pp. 632–3; T. C. Chamberlin, *Ann. Rept. Wis. Geol. Surv.* 1878, pp. 21–5; T. C. Chamberlin and R. D. Salisbury, *Sixth Ann. Rept. U.S. Geol. Surv.* 1885, pp. 199–322.

may, perhaps, have a more remote explanation and a broader significance in connection with the two centres of origin above discussed. The suggestion is, that the great track of the Labradorian currents was through the Huron-Erie and Michigan Valleys, while the chief track of the current from the Hudsonian centre was down the Dakotan and central Iowan basins, making it easy for slight local causes to bring about a separation of the two currents along the zone that lay between these great thoroughfares of the ice.

A very much smaller but interesting area free from drift has been found by Professor Salisbury in the little peninsula lying between the Illinois and Mississippi rivers just above their junction. It has a similar relation to the two great movements.

The Cordilleran Glacier.—According to Dr. G. M. Dawson, the central névé of the confluent Cordilleran glaciers lay between the 55th and 59th parallels of north latitude, and occupied the plateau between the coast-ranges and the Rocky Mountains. From this central tract there was a general ice-movement south-eastward for 600 miles and north-westward for about 350 miles. The southern limit of confluent glaciation lay a little south of the Canadian boundary between the 48th and 49th parallels of north latitude. It thus fell about 10° short of the low latitude reached by the Laurentine glacier on the much lower ground of the Mississippi Valley. The north-westerly movement invaded the upper Yukon basin, and reached to about 62° or 63° north latitude. On the west side many tongues of ice reached the Pacific, being reinforced, it would appear, from local centres of glaciation along the coast-ranges and on the coast-islands.[1] On the east side there were local centres of accumulation on the heights of the Rocky Mountains, and these thrust tongues down many of the valleys and to some extent out upon the plains. There was, however, no general overflow of the interior Cordilleran névé across the Rockies to the great plains. The Cordilleran tract, therefore, while a very important one, was not a general centre of radiation in any such sense as the Laurentian uplands or Scandinavia.

The Inland Ice of Greenland.—There is little evidence to

[1] Dr. G. M. Dawson, *Trans. Roy. Soc. Can.*, and other papers.

show whether the inland ice of Greenland in Pleistocene times was more or less extensive than at present. That it formerly covered the narrow border of land that now lies between it and the surrounding waters is not doubted, but whether that extension was contemporaneous with the more southerly glaciations of the Ice Age, or merely an episode of a later stage connected with the existing glaciation, is not so unquestionable. It is a fair assumption, however, that in glacial times the ice of Greenland completely buried the land and, perhaps, protruded itself beyond. But whether it became confluent with the glaciation of the Arctic islands lying just west of it, or with that of the mainland of America, we do not know. The evidences of an easterly movement in the north Hudson Bay region and along Hudson Straits, and the absence of evidence of a cross movement from the north and north-east, taken in connection with the great capacity of the valley occupied by Baffin Bay and Davis Strait, render an extension to the mainland doubtful.

THE IMBRICATION OF THE DRIFT SERIES.

The drift deposits of the great plain region of North America may be looked upon as a series of sheets overlapping each other in imbricate fashion; the outermost disappearing beneath the next inner, and this, in turn, dipping beneath the succeeding, and so on. The outer uncovered zone of each sheet retains its original form, except as modified by superficial agencies, but the inner buried zone was much modified by the over-riding ice during the later advances. In a general view of the drift, it is important to grasp clearly this conception of the overlapping of the sheets, and to distinguish this imbricate structure from the simple stratigraphical superposition of marine sediments on the one hand, and of simple morainic corrugations following each other in concentric recessional lines on the other. It is, furthermore, important to observe that this is only a superficial conception of the drift series. Theoretically, there are at least two of these imbricate series for every period of glaciation, and the order of imbrication takes on opposite phases. During the first part of the glaciation, when the ice on the whole was

extending, though by alternate advances and retreats, the later were generally greater than the earlier advances. During the succeeding stage, however, when the ice was, upon the whole, retiring (though by oscillations), the later advances generally fell short of the earlier. In the case of the lower or older series of glacial accumulations therefore, the later deposits generally reach farther south than the earlier ones, whereas, during the recessional stages of glaciation, the earlier sheets extend farther south than the later. These two imbricate series of sheets of contrasted order represent the two great halves of a period of glaciation. If there were two or more entirely distinct periods of glaciation, theoretically the double imbricate series repeated itself accordingly. The older, or lower series, is, as yet, scarcely known to us, and therefore will receive little consideration here; but it ought not to be overlooked in a comprehensive view of the history of glaciation, nor should it be forgotten that the deposits we usually call earliest for convenience are really only those of maximum glaciation—the mid-winter of the Glacial Period. (See Frontispiece.)

The extent to which the imbrication of the glacial deposits was developed obviously depended not only upon the extent of the oscillations of the ice-margin, but also upon the intensity of the ice-action. If, with every advance, the ice pushed all loose débris in front of it, imbrication or overlapping would entirely disappear, and a series of concentric moraines would be all that would be left. From these, only the history of the retreat, and that partially, could be worked out. It is obvious, therefore, that the morainic habit and the imbricate habit stand in antagonistic relations.

As a matter of observation, both of these habits found large expression in the glacial deposits of America. The imbricate habit was predominant in the earlier stages, as found represented in the Mississippi basin, and the morainic habit predominated in the later stages. This was so notably true that the earlier known drift-sheets show but very slight morainic ridgings, and were not greatly disturbed nor abraded by the superposition of the borders of the succeeding deposits. The margins overlap for considerable distances without great disruption of the underlying bed. In the region of later

drift, where the morainic habit prevailed, very considerable overlapping of the sheets may be demonstrated; but the abrasion and disturbance of the overridden sheets was much more marked, and the under sheet only retains its integrity for a comparatively narrow zone.

Before taking up the members of the overlapping series, a few words may be said regarding the constituents and structure of the drift.

The Constituents of Drift Deposits.—The structural characteristics of the glacial formations of America are so closely similar to those of Europe that it is needless to repeat elementary details already familiar. There are some differences in the general aspect of the formations of the two continents, but these are only such as naturally grew out of the different conditions of their development and the variation in the materials wrought upon. The American area is the larger, and therefore its formations are developed upon a more gigantic scale, and, as a result, take on more pronounced characteristics in many particulars. Differences, which in a less ample expression of the formations would not be notable, become conspicuous in the larger development. These differences, and some observations on the prevalence and distribution of special forms, are all that claim serious attention here.

The Till.—The greatest constituent of the American drift consists of stony clays, interpreted as the direct product of ice-action. These are as closely identical with the tills of Europe as could well be imagined when account is taken of local conditions and constituents. If a gigantic mosaic were formed of patches of till taken indiscriminately from the two continents, it would be necessary to resort to the local rock constituents to detect the individual sources of derivation.

The till-sheets of the great plains of America have much persistency, and, while not uniform in thickness, nor entirely continuous, the irregularities and the interruptions are less notable than the continuity and general uniformity presented. This does not hold good of the border-tracts of the old drift, which are very uncertain in presence and patchy in distribution, nor of the inner border of the individual till-

sheets where they were overridden by later ice-incursions and suffered therefrom.

Notwithstanding this somewhat general uniformity and continuity, it is difficult to give a reliable estimate of the thickness of any given sheet. The territory is so vast in proportion to the number of measurements that have been made, that any estimate now possible must be held subject to correction. It may suffice for a general approximation to regard the individual sheets as having average thicknesses ranging from twenty to sixty feet. As these sheets overlap each other in imbricate form, the total thickness in the submarginal zone which has been chiefly studied, and where the overlapping is most prevalent, is usually much more than this. The maximum thickness at given points is very much greater. In a few places, it is known to exceed 500 ft.[1] It probably has an occasional thickness of 600 or 700 ft., and may possibly reach 1,000 ft. or more. (We are here speaking solely of the deposits of the Laurentide glacier. Mr. Russell has shown that the Alaskan drift at the foot of the St. Elias range reaches the extraordinary depth of 4,000 ft.[2]) There are perhaps a score of measurements exceeding 400 ft.; half a hundred or more exceeding 300 ft.; and one hundred or more exceeding 200 ft. The average thickness for the upper Mississippi basin may perhaps be put at present at the round figure of 100 ft., though this is probably an under-estimate. The same estimate may be made for the south-western tract of Ontario and of the southern portion of the great north-western plains of Canada, though the data there are more scanty. What may be true of the great Mackenzie basin is unknown, though Mr. McConnell's observations would seem to put it in the same class as the preceding. In the hilly regions of Pennsylvania, New York, New England, and the south-eastern provinces, the drift distribution is very much more irregular, and an estimate of the average thickness correspondingly difficult and uncertain.

[1] St. Paris, Ohio; Edward Orton, *Geol. of Ohio*, vol. vi. p. 277 (530 ft., bottom not reached); near Gowanda, New York, Frank Leverett, MS.; south of Seneca Lake, New York, T. C. Chamberlin, *Third Ann. Rept. U.S. Geol. Surv.* p. 355; R. S. Tarr, *Bull. Geol. Surv. of Am.* vol. v. p. 353; Dundas Valley, J. W. Spencer, *Geol. Surv. of Pa. Rept. Q.* 4, pp. 384-5.

[2] *Am. Journ. Sci.* vol. xliii. March 1892, p. 174.

Apparently it is much less than in the upper Mississippi region. If Mr. Chalmers' view, that the glaciation of New England was essentially local, be correct, this more meagre development will not appear strange.

From what is known of the Laurentian tract of Canada, it would appear that the drift there is, in general, very thin. This accords with the fact that the region in question was the source of dispersion, and was robbed by the ice-currents to the profit of the surrounding plains of the Dominion and the States, over which the spoils were strewn. The superior thickness in the upper Mississippi Valley is doubtless due, in part, to the concentration there of currents flowing in not only from the north, but from the north-east, through the Laurentian valley, and from the north-west, through the Red River Valley, as already noted; or, perhaps, taking a larger view, to the concentration there of the drift borne in by currents from both the Labradorian and the West-Hudsonian sources of dispersion.

Terminal Moraines.—While there are medial and lateral moraines in the mountainous regions of the west, and to some extent in the east, as a result of the local glaciers that followed the greater ice-extension, such moraines are rare in the main area of Laurentide glaciation. Terminal moraines, however, attain an extraordinary development, taking on much variety of expression, and reaching sizes truly gigantic. Some of these have been traced several hundred miles in individual distinctness, and, by fair correlation, may be assumed to have been identified for a thousand miles or more. At intervals, however, they come into conjunction with other moraines, sometimes overriding, sometimes being overridden by these, at other times coalescing with them, so that it is difficult to follow individual moraines in absolutely demonstrative continuity for very great distances. The doubt respecting the correlation of particular moraines does not attach equally to the groups or belts which they form by their union. The chief of these complex belts has been traced from the Atlantic coast over the Appalachians, across the broad Mississippi basin, and far out upon the north-western plains of Canada. Observations here and there indicate its probable extension to the Arctic seas.

Some of these complex terminal moraines are majestic in dimensions and indescribably intricate in structure, forming great irregular thickened zones of hummocky drift from three to five or even ten or fifteen miles in breadth, and from 100 to 500 ft. in depth. They are characterised by tumultuous hills of exceedingly irregular contours, their surfaces being diversified with knobs and basins that give intricacy to the larger irregularities.

There is a variety of terminal moraines, however, relatively free from rugosities of surface, for they are little more than broad, smooth, massive, semi-cylindrical swellings or banks of drift. As topographic features, these are not impressive; but when their breadth and depth and their continuity over wide areas are duly weighed, they appear as really great moraines.

A third, but not abundant, variety consists of narrow abrupt ridges resembling the little frontal windrows of Alpine glaciers. These are relatively rare on the great plains, but are more frequent in the hilly and mountainous tracts.

From these notable types we can trace gradations into obscure lines of marginal accumulation scarcely recognisable as terminal moraines. Tracking the former outlines of the ice by means of these last is attended with difficulty and uncertainty, while the great moraines mark out the stages of glaciation with much distinctness.

There seem to be three elements in the composition of the more complex terminal moraines, which may be best characterised by the method of their formation. (1) Material that was borne within and upon the ice was carried out to the edge and dropped there, forming a marginal ridge for which the name 'dump moraine' has been suggested.[1] (2) Material which was pushed or dragged along the bottom of the glacier was permitted to lodge as it approached the edge, because of the lack of power in the thin weakening border of the ice to force it any further. For such an accumulation just under the ice-border, the name 'lodge moraine,' or 'submarginal moraine,' has been suggested; submarginal, in the double sense of being formed under the ice-edge and of being formed along a line not strictly

[1] T. C. Chamberlin, *Geol. Soc. Am.* Toronto, vol. i. (1889), p. 28.

marginal to the ice. (3) The advancing edge of the ice under favourable conditions pushed or ploughed up material along its front causing a ridge by direct thrust, to which the name 'push moraine' has been applied.

All these forms are often present, and it is their combined effects (with the attendant water-action) that give the great complexity and massiveness to the gigantic terminal moraines. Often one of these factors was absent, and sometimes two. The ice appears not always to have had the power of forcibly thrusting up the débris at its edge, and the result was the lodgment of the basal material at points beneath, but near, the ice-edge, while the englacial [intraglacial] and supra-glacial material was carried out to the border and dropped upon the surface. As this englacial [intraglacial] and supra-glacial material seems to have been very largely composed of coarse rocky débris derived from prominences in the north, the dump moraines frequently become little more than tracts of thickly-strewn boulders. In some instances these boulder-belts are all the marginal morainic representatives that can be detected over considerable tracts. This occurs chiefly on smooth plains gently sloping in the direction of the ice-movement, and therefore furnishing little opportunity for vigorous ridging.

In the Mississippi basin, where the terminal moraines have been most fully worked out, they are disposed in great loops or festoons, showing that the ice had a pronounced lobate outline. The re-entrant angles between the lobes of the ice were sometimes strangely prolonged. In such cases, the ice-current in the sides of the adjacent lobes flowed towards each other, and, by such opposing movement, formed inter-lobate moraines. These are not lateral moraines in the usual sense of that term, as they are sometimes misunder-stood to be. They belong to the terminal class, and are peculiar chiefly in the conditions under which they were formed. The sides of the adjacent ice-lobes formed a gigantic trough into which the common drainage of the lobes flowed, giving rise to unusual glacio-fluvial phenomena. Kames are especially abundant in connection with such moraines. Where a close succession of terminal moraines is formed, they are usually more or less coalescent in these

re-entrant angles, or, if not really coalescent, they become confused; and hence the positive identification of a moraine before and after it enters this angle of confusion is often difficult.

The successive advances and retreats of the ice-border were not always parallel to each other, though the influence of a constant topography tended to bring them into conformity even when of widely different ages. Sometimes, in spite of this topographic influence, the successive borders were very far from being parallel. Later moraines sometimes run across earlier ones at large angles, even right angles. In such cases, the earlier moraines may usually be traced for some distance within the overridden territory, but usually they soon become so obscure as to prevent further following.[1]

When we come to discuss the glacial succession, we shall speak further of the terminal moraines and their relationships. For a general view of their distribution, the reader is invited to consult the accompanying map (Plate XV.).

Drumlins.—The American drumlin-forms appear to be in every essential respect like those of Scotland and Ireland. In harmony with the more gigantic development of the American phenomena, the drumlin-tracts are larger and the drumlins themselves, on the whole, perhaps more massive. The lenticular form may be taken as the type, but from this they grade into elongated forms, some of which have lengths of three or four miles. On the other hand, they grade into shorter forms of more nearly circular base and mammillary configuration. On the northern border of the Wisconsin

[1] References relative to Moraines—C. Whittlesey, *Smithsonian Contributions*, 1866; G. M. Dawson, *Quart. Journ. Geol. Soc.* Nov. 1875, p. 614; T. C. Chamberlin, *Trans. Wis. Acad. Sci.* vol. iv. (1876–7), pp. 201–234; *Proc. Int. Cong. Geologists*, Paris, 1878; *Third Ann. Rept. U.S. Geol. Surv.*, 1881–2, pp. 291–402; *Amer. Journ. Sci.* vol. xxiv. (1882), pp. 93–97; R. D. Irving, *Wisconsin Geol. Surv.* vol. ii. (1877), pp. 615–634; G. H. Cook and J. C. Smock, *New Jersey Geol. Surv.* 1876–7, 1877–8; C. H. Hitchcock, *New Hampshire Geol. Surv.* vol. iii. (1878), pp. 218, 230–6, 246, 301–5, 337; Warren Upham, *Amer. Journ. Sci.* 1879, pp. 81–92, 197–209; *Minnesota Geol. Surv.* vol. i. (1884), pp. 406, 462, 478, 484, 495, 505, 520, 527, 633; *Can. Geol. Surv.* vol. iv. 1889, pp. 44–5 E; *Proc. Amer. Assoc. Adv. Sci.* vol. xxxii. (1883) pp. 213, 232; *Rept. Minn. Geol. Surv.* 1880, pp. 281–356; C. E. Sweet, *Wisconsin Geol. Surv.* vol. iii. (1880), p. 384; I. C. White, *Pennsylvania Geol. Surv.*, 1880, p. 26; N. H. Winchell, *Ohio Geol. Survey*, vol. ii.; *Minnesota Geol. Surv.* vol. i. (1884), pp. 377, 385, 544, 660; Lewis and Wright, *Second Geol. Surv. Pennsylvania, Rept.* 1882; J. B. Tyrrel, *Amer. Geol.* vol. viii. pp. 19–28 (1891); Dr. Robert Bell, *Bull. Geol. Soc. Amer.* pp. 303, 306.

drumlin-tract there are small cones, like tumuli, often not more than three or four rods in diameter and from five to ten feet in height, which are made up largely of rocky material, and which may possibly prove to be drumlins in embryo. They have not yet received careful study, however, in the light of this suggestion.

On the islands of Boston harbour and in the adjacent portions of Massachusetts, and in south-eastern New Hampshire, as also in the central part of Massachusetts and in north-eastern Connecticut, there are many very typical drumlins[1] of the lenticular variety. These New England drumlins are composed, as all typical drumlins are, chiefly of unassorted drift; but some of them, as shown by Mr. Upham and others, have stratified material in their bases. Professor Shaler has noted that not a few have pedestals of rock. But neither stratified materials nor rock-nuclei seem to be constant elements of the drumlins here or elsewhere. Drumlins also occur in Maine and New Brunswick. In central New York, between Batavia and Rochester, there is a very notable area of drumlins in which the elongated type is predominant. They are occasionally several miles in length.

The most extensive, and, taken all together, perhaps the most remarkable drumlin-area is found in eastern Wisconsin. It lies, in part, within the lobate tract overrun by the Green Bay glacier, and, in part, within the western border of the territory of the Lake Michigan glacier. In the former tract,

[1] Papers on Drumlins—James Hall, *Geology of the Fourth District of New York*, 1873, pp. 414-5; I. A. Lapham, *Smithsonian Contributions* for 1855; N. S. Shaler, *Proc. Bos. Soc. Nat. Hist.* 1870, pp. 196-264; C. H. Hitchcock, *Ibid.* vol. xix. (1876) pp. 63-67; G. F. Matthew, *Geol. Surv. Can. Rept.* 1877-9, pp. 12-14, EE; Warren Upham, *Proc. Bos. Soc. Nat. Hist.* 1879, pp. 220-234; *Ibid.* vol. xxiv. (1889) pp. 228-242; *Geology of New Hampshire*, vol. iii. (1878); *Am. Geol.* vol. x. (Dec. 1892) pp. 339-360; *Bull. Geol. Soc. Am.* vol. iii. (1892) p. 142; G. H. Stone, *Proc. Bos. Soc. Nat. Hist.* vol. xx. (1880) p. 434; *Ibid.* (March 11 and Nov. 21, 1881); L. Johnson, *Trans. New York Acad. Sci.* vol. i. (1882) pp. 78-89; *Annuals New York Acad. Sci.* vol. ii. pp. 249-266; T. C. Chamberlin, *Geology of Wisconsin*, vol. i. (1883) p. 283; *Proc. Am. Assoc. Adv. Sci.* 1886, p. 195; *Third Ann. Rept. U.S. Geol. Surv.* 1883, p. 306; J. D. Dana, *Am. Journ. Sci.* vol. xxii. (1883) pp. 357-361; W. M. Davis, *Ibid.* Dec. 1884, pp. 407-416; Robert Chalmers, *Geology of Canada, Rept.* 1888-9, vol. iv. p. 23, N; R. D. Salisbury, *Geological Survey of New Jersey, Rept.* 1891, p. 74; D. F. Lincoln, *Am. Journ. Sci.* vol. xliv. (1892) pp. 293-6; J. B. Tyrrell, *Bull. Geol. Soc. Am.* vol. i. (1890) p. 402; G. H. Berlin, *Am. Geol.* vol. xiii. (March 1894) p. 224; Frank Leverett, *MS. Rept.* 1893. Extends drumlins west to the vicinity of Batavia in a well-defined belt; scattered drumlins between Lockport and Niagara Falls.

the ice-currents diverged from the axis of the lobe toward its borders and the axes of the drumlins are disposed in like manner, giving, when plotted, a beautiful illustration of the axi-radiant flowage which finds so remarkable expression in the Green Bay ice-lobe. In the central portion of the tract the elongated types predominate, while towards the border the shorter forms more commonly prevail. Nearly the whole ground covered by the southern portion of the ice-lobe is occupied by these drumlins, whose total number Mr. Buell estimates at 10,000. On the western side of the Lake Michigan tract the drumlins trend in an east-west direction. As those of the adjacent Green Bay lobe trend from north-west to south-east, the two sets give a beautiful demonstration of the antagonistic movements of the two adjacent ice-lobes. Between these two drumlin-tracts lies the great interlobate 'Kettle moraine' formed by the combined action of the ice-lobes of Green Bay and Lake Michigan.

In the upper peninsula of Michigan, west of the great Bay de Noque, there lie some very fine examples of elongated drumlins. They are perhaps to be reckoned a part of the Green Bay system. In the north-western territory of Canada, Mr. Tyrrell has found drumlins on the islands in Lake Winnipegosis and those of Cree lake, and in isolated instances elsewhere.

All these tracts of pronounced drumlins lie north of the chief belt of terminal moraines and evidently belong to the later glaciation. On the outside of these moraines there is generally an absence of drumlins; but this statement must not be pressed so far as to mean the entire exclusion of drumlin-like forms, or even of some fairly well-developed drumlins. So far as is known, the nearest approach to well-formed drumlins outside of the great moraines is found in connection with a drift of intermediate age, close to the southern line of Wisconsin. In south-western Illinois there are drift-hills with flowing contours that take on some resemblance to drumlins, but it is doubtful whether they should be classed as such.

Åsar or Eskers.—These terms are here restricted to the long gravel ridges which conform, in general, to the direction of the ice-movement, and which are thought to repre-

sent the main drainage lines of the glaciers in their later stages, particularly when they approached a stagnant condition. The term kames, on the other hand, is applied to those gravel accumulations which take on the form of bunchy aggregations of knolls and irregular ridges, and have a tendency to arrange themselves in belts parallel to the margin of the ice. They frequently accompany terminal moraines and have a quasi-morainic aspect. This distinction has gained some acceptance in America and proves very serviceable.[1] It is not to be understood that any sharp line of distinction can be drawn between the two types. They are connected by intermediate forms which are difficult to place in either class. The kames, as well as the eskers, are regarded as products of glacial drainage. The genetic ground of distinction between the two classes is believed to lie in the different conditions under which the glacial drainage acted; the kames being associated with vigorous ice-action, and hence representing chiefly marginal glacio-fluvial deposition. The åsar or eskers seem to represent very inactive conditions of the ice and to be less closely confined to the margin, and thus to represent the internal, rather than the peripheral drainage of the ice. As between the alternative terms åsar and eskers, the former has the sanction of priority, and is the local term for the great Scandinavian type. Notwithstanding this, the term esker is growing into favour among American glacialists, doubtless for phonic reasons.

There are some American instances in which the eskers, on reaching the border of the ice, turn abruptly through a large angle and run for some miles parallel to its edge, after the fashion of some of the Scandinavian åsar. There are also some elongated ridges whose whole courses lie essentially parallel to the edge of the ice and which yet retain the distinctive characteristics of åsar. It seems not improbable, therefore, that it may be advisable to recognise a class of transverse åsar, distinguished from kames proper by their structural characteristics and by the conditions of the ice at the time of their deposition.

The American eskers conform apparently in every essen-

[1] [The reader will remember that the same distinction has been observed in the descriptions given of the equivalent deposits in Europe, see Chaps. XIV.-XVII.—J.G.]

tial respect to the typical åsar of Sweden. They have their finest development in Maine, where they have been specially studied by Mr. Stone.[1] He has worked out thirty-one separate systems, some of which are very considerably branched. The longest system has a stretch of about 150 miles. Their heights commonly range from fifteen to a hundred feet, but occasionally reach 140 ft. This esker area extends easterly into New Brunswick, where it has been studied by Mr. Chalmers and others. There are occasional representatives elsewhere in the maritime provinces. Eskers occur frequently in central and western New England. The tendency there, however, is toward aggregation in clustered hills of the kame type, or to irregular aggregations of doubtful classification. In the Middle States, where hilliness prevails, a similar tendency is predominant, although typical eskers are not uncommon. On the plains of the interior they are not frequent, but some admirable examples occur. Some of these terminate in well-defined delta fans. Mr. Leverett has noted that some of these eskers occupy valleys cut in the drift. Eskers also occur sparingly in Canada, both in the St. Lawrence basin and on the north-western plains.

Kames.—Kames of the typical order are abundant along most of the great terminal moraines from the Atlantic to the basin of the Saskatchewan. They are intimately associated with the moraines, and bear evidence of having participated in the combination of actions by which the moraines were formed. They grade into aggregations of partially assorted material, and incorporate within themselves wholly unassorted till, so that they are bound by inseparable links to the true morainic accumulations. Taken as a class, they may be interpreted as semi-morainic formations. They are peculiarly abundant and pronounced in character in the interlobate portions of the terminal moraines, for the obvious reason that glacio-fluvial action was greatly concentrated there.

Besides those associated with typical moraines, many such knolls and ridges are found in the hilly regions, where they are variously arranged, though usually grouped in the valleys. Not infrequently they form belts, which swing

[1] George H. Stone, 'The Kames of Maine,' *Proc. A. A. A. S.* 1880, p. 511.

across the valleys with a curve precisely like that of terminal moraines. In most of such cases, although, owing to the preponderance of fluvial over glacial action, they are composed of assorted materials, yet they are doubtless, in effect, true terminal moraines. Similar belts and clusters are sometimes found in the plain regions, unassociated with till-moraines, but such are more rare.

Quite independently of any evident association or arrangement, isolated knolls, some of them mere tumulus-like heaps, and isolated clusters of gravelly hills and ridges are found scattered over both the hilly and plain tracts of drift, and doubtless represent the minor and merely incidental drainage work of the glacial waters.[1]

Pitted Plains or Sand Plains.—It has been noted that the esker ridges sometimes terminate in delta-fans caused by the spreading out of the glacial streams when they emerged at the edge of the ice, and the consequent deposition of their detritus. The edge of these plains next to the ice is frequently undulatory, doubtless due to the burial of ice under the edge during their formation and its subsequent melting. It is possible that some of the irregularity may be due to

[1] References relative to Kames and Eskers—E. Hitchcock, *Elementary Geology*, 1857, pp. 260-3; J. Shaw, *Ill. Geol. Surv.* vol. v. (1873) pp. 107-110; *Minn. Geol. Surv.* vol. i. (1884) pp. 417, 444, 464, 582, 624; J. S. Newberry, *Geol. Surv. Ohio*, vol. ii. (1874) pp. 41-6; vol. iii. (1878) pp. 40-2; A. C. Lindemuth, *ibid.* p. 503; Warren Upham, *Proc. Amer. Assoc. Adv. Science*, 1876, pp. 216-225; *Amer. Journ. Sci.* vol. xiv. (1877) p. 459; *Geol. of New Hampshire*, vol. iii. (1878) pp. 3-176; *Amer. Geol.* vol. viii. (1891) p. 321; T. C. Chamberlin, *Geol. of Wisconsin*, vol. ii. (1877); *Third Ann. Rept. U.S. Geol. Surv.* 1881-82, p. 299; *Amer. Journ. Sci.* vol. xxvii (1884) pp. 378-390; G. H. Cook, *New Jersey Geol. Surv.* vol. i. (1888) p. 116; G. F. Wright, *Proc. Boston Soc. Nat. Hist.* vol. xx. (1878-80) pp. 210-220; *Ice Age in North America*; W. J. McGee, *Proc. Amer. Assoc. Adv. Sci.*, vol. xxvii. (1878) pp. 198-231; *Eleventh Ann. Rept. U.S. Geol. Surv.* 1889-90; G. H. Stone, *Proc. Boston Soc. Nat. Hist.* vol. xx. (1880), pp. 430-469; J. D. Dana, *Amer. Journ. Sci.* vol. xxii. (1881) pp. 451-468; vol. xxiii. (1882), pp. 179, 360; vol. xxiv. 1882, p. 98; C. H. Hitchcock, *Proc. Amer. Assoc. Adv. Sci.* vol. xxxi. (1884), p. 388; H. C. Lewis, *Rept. Second Geol. Surv. Pennsylvania*; *Rept. Brit. Assoc. Adv. Sci.* 1884, p. 720; *Proc. Philad. Soc. Nat. Hist.* 1885, pp. 157-173; N. S. Shaler, *Proc. Boston Soc. Nat. Hist.* vol. xxiii. (1884), pp. 36-44; *Ninth Ann. Rept. U.S. Geol. Surv.* 1887-88, pp. 549-550; *Bull Mus. Comp. Zool.* vol. xvi. pp. 203-5; N. H. Winchell, *Minn. Geol. Surv.* vol. i. (1884), pp. 388, 665; Ells, *Ann. Rept. Geol. Surv. Canada*, 1885, p. 653; N. O. Holst, *Amer. Nat.* vol. xxii. (1888), p. 589; W. O. Crosby, *Physical History of Boston Basin*, 1889; J. H. Chapin, *Trans. Meriden Sci. Assoc.* Jan. 1891; R. D. Salisbury, *Ann. Rept. New Jersey Geol. Surv.* 1891, pp. 89-92; I. C. Russell, *Amer. Geol.* vol. xii. (1893) p. 232; E. P. Gulliver, *Journ. Geol.* vol. i. (1893) pp. 803-812; W. M. Davis, *Bull. Geol. Soc. Amer.* vol. i. pp. 195-202; *Proc. Boston Soc. Nat. Hist.* vol. xxv. pp. 478-499; Bouvé, *Ibid.* p. 173.

oscillations of the edge of the ice, but, in general, the ice-border appears to have been essentially stagnant during the formation of the typical eskers. In an analogous fashion, there are plains of sand and gravel associated with the kames on their outer side, that is, the side away from the ice. These were doubtless formed in a similar way by deposition from the glacial waters as they escaped from the edge of the ice. There are instances in which such plains of sand and gravel accumulated without any obvious association with either kames or eskers. The method of production was doubtless the same, but the conditions for deposition within the ice-walls were absent, and the glacial waters only threw down their burden when they escaped from the edge of the ice. Such plains usually present on their iceward side abrupt declivities which were formed irregularly through the melting away of the ice against which they were originally banked, and which, to some extent, they overspread. The melting of buried masses of ice naturally gave rise to pits and hollows. In some regions, notably northern Michigan, Wisconsin, and Minnesota, there are great tracts overspread by sands and gravels marked with pits ranging from a few rods in diameter to a mile or more, which are perhaps to be referred to similar action, but their great extent and the number and size of the depressions leave some room for doubt whether this is an adequate explanation.[1]

Glacio-Fluvial Aprons and Valley-Drift.—Whenever the ice stood under favourable conditions for any notable length of time at any one point, the waters issuing from it made deposits along its margin, which were usually thickest and coarsest next to the ice and thinner and finer at increasing distances from it, until the deposit faded out or was gathered into the valleys. Professor Shaler has aptly styled such fringing deposits, 'frontal aprons.' They are especially associated with terminal moraines, being overwash deposits. As the waters issuing were usually soon gathered into the main drainage-lines, the deposits are found to merge into valley-trains which follow the drainage-lines to varying

[1] References relative to Sand Plains—T. C. Chamberlin, *Geol. of Wisconsin*, 1873–80, vol. iv.; F. H. King, *ibid.* pp. 585–615; W. M. Davis, *Bull. Geol. Soc. Amer.* 1890, vol. i. pp. 195, 202; F. P. Gulliver, *Journ. of Geol.* vol. i. (1893) p. 803; F. H. Bradbury, *Illinois Geol. Surv.* vol. iii. pp. 189, 225.

distances, usually, in one form or another, to the sea. The aprons and the valley-trains are, therefore, genetic units, but all valley-trains do not head in aprons. Theoretically, all aprons should gather into trains ; but this did not actually take place when the ice-edge lay close to the sea, as in the case of the Long Island apron.

The aprons and valley-trains are sometimes formed of sand and gravel, and sometimes of fine silt, their composition being obviously dependent upon the vigour of the drainage. Both aprons and valley-trains have a large and very significant development in connection with the American drift-deposits. They are significant in that they indicate the volume and freedom of the drainage attendant upon the glaciation, and throw light at once upon the atmospheric and the topographic conditions. The great gravel aprons and coarse valley-trains indicate measurably vigorous, but not excessive drainage. The very fact that the valleys were filled to great depths with such a deposit indicates that the drainage was either moderate in amount relative to the burden of detritus, or that the slope was not steep. On the other hand, the presence of widespread sheets of fine silt indicates the presence of abundant waters and low slope.

Aprons of one kind or another are the almost universal attendants of the great terminal moraines already described. Those which accompany the most pronounced of these are usually sandy and gravelly. Notable examples are found along the south side of the Long Island moraine and on the outer slopes of Nantucket and Martha's Vineyard, and similarly bordering the moraine as it crosses New Jersey and extends westward. In the hilly territory of the Appalachians the aprons are very discontinuous, and the more pronounced valley-trains head on the outer side of the moraines in gravel-sheets not much wider than the main valleys ; but on the great plains of the interior the overwash is more generally distributed and the aprons are almost universally present. Similar aprons accompany the inner moraines, but usually they have a less pronounced development, owing doubtless, in part, to the minor importance of these moraines, and, in part, to the less favourable topographic conditions.

Some of the smoother moraines have aprons of silt and sand, without gravel, indicating a slower drainage. These are not all confined to one age, and are so distributed as to indicate the absence of very steep gradients at several different stages of the moraine-forming period.[1]

Löss.—The silt aprons, or overwash sheets, in the flatter country of the Mississippi Valley seem to spread very widely over the country and to merge into mantles of löss-like appearance. It can hardly be stated at present that any typical löss sheet can be traced into direct and demonstrable continuity with an overwash apron associated with a definite terminal moraine. The löss deposits of the Mississippi Valley consist of wide sheets usually bordering the great drainage-lines, being thickest and coarsest near the rivers, and passing gradually away into thinner and finer deposits, the precise termination of which is fixed with difficulty. To a considerable extent these silt mantles sweep over all the territory between the main streams, as between the Wabash and the Illinois rivers in the central part of the state of Illinois, between the Illinois and the Mississippi rivers, and between the Mississippi and the Missouri rivers across southern Iowa. Traced northward, they have two typical methods of disappearance. In the first, they pass under later deposits, following the law of imbrication previously noted. In such instances, they are either overspread by later silts issuing from the edge of the ice that overrode them, or are covered with coarser glacio-fluvial depositions, or by till. The second method consists of a somewhat abrupt termination adjacent to what appears to have been the position of the edge of the ice at the time of the formation of the silt. This edge is often very irregular in outline, being almost digitate. The best illustrations by far are those described by Mr. McGee,[2] in north-eastern Iowa. The löss usually thickens and becomes much coarser as it approaches this digitate border. Reference is here made only to the chief of the sheets of silt that take on the

[1] References relative to Aprons or Gravel Plains—N. H. Winchell, *Minnesota Geol. Surv.* vol. i. (1884) p. 118; C. H. Hitchcock, *New Hampshire Geol. Surv.* vol. i. (1874) p. 542; J. S. Newberry, *Ohio Geol. Surv.* vol. iii. (1878) p. 40; R. D. Salisbury, *Ann. Rept. State Geol. New Jersey*, 1891, 1892, 1893.

[2] W. J. McGee, *Eleventh Ann. Rept. U.S. Geol. Surv.* 1891, pp. 435-471.

löss-like constitution. There are subordinate deposits of silt of more or less löss-like aspect that belong to different stages of glaciation, and were formed under varying and perhaps rather local conditions.

Reservation is also to be made for löss-like deposits through the agency of wind. It seems probable that some of the deposits of the Mississippi Valley are of æolian origin, having been produced perhaps simultaneously with the water-deposit by the action of the wind upon the mud flats exposed and dried during the intervals between glacial floodings. It is the impression of several careful observers that even a part of the löss associated immediately with the rivers is so formed, but this æolian löss has not as yet been successfully differentiated from the glacio-fluvial löss. The formation of the löss will be referred to later in noting the succession of glacial deposits.[1]

[1] References relative to Löss—James Shaw, *Illinois Geol. Surv.* vol. v. (1873) pp. 29, 144, 171; A. H. Worthen, *Ibid.* vol. vi. (1875) pp. 37, 66, 213; R. Pumpelly, *Amer. Journ. Sci.* 1879, vol. xvii. pp. 133-144; Warren Upham, *Minnesota Geol. Surv.* 1880, pp. 314-323, 338; McGee and Call, *Amer. Journ. Sci.* vol. xxiv. (1882), pp. 202-223; T. C. Chamberlin and R. D. Salisbury, *Sixth Ann. Rept. U. S. Geol. Surv.* 1884-5, p. 278; W. J. McGee, *Eleventh Ann. Rept. U.S. Geol. Surv.* 1889-90, pp. 291-303; R. D. Salisbury, *Arkansas Geol. Surv.* vol. ii. (1889) pp. 225-231; I. C. Russell, *Geol. Mag.* III. (1889). vol. vi. pp. 289-295, 342 50; O. H. Hershey, *Amer. Geol.* vol. xii. No. 5 (Nov. 1893), pp. 314-323.

CHAPTER XLII.

GLACIAL PHENOMENA OF NORTH AMERICA—*continued.*

Succession of glacial deposits—Subdivisions of the glacial formation—The Kansan formation—The post-Kansan interval—The East-Iowan formation—Correlation with coastal formations—Interval following the East-Iowan formation—The East-Wisconsin formation—The Toronto fossiliferous beds—The Champlain deposits—Chronological interpretations.

WE know very little about the advancing stages of the ice-invasion. Theoretically, the stages of incursion should be as prolonged, complex, and important as the stages of retrocession. Indeed, if we may trust to the analogy of our annual episodes of glaciation, the incoming of the great Pleistocene winter should have been rather more prolonged than its outgoing, and the struggle between the conflicting forces, and the consequent oscillations of ice-front, more pronounced. This appears all the more probable if we draw an analogy from the arctic seasons in which the approach of the winter is prolonged; while that of summer, after the tide of the season has once turned, is surprisingly rapid. The record of the oncoming Pleistocene glaciation is very imperfect, for the ice continually gained territory, and overrode and measurably destroyed the integrity of its earlier deposits. Doubtless there are remnants of these deposits, but they are hard to reach, and still more difficult to interpret. Here and there, buried beneath more superficial drift-sheets, appear glacial deposits obviously old, and these may, perhaps, be remnants of accumulations formed during the early stages of invasion, but it is difficult, if not impossible, to prove this. We must content ourselves for the present, therefore, with merely recognising the probability of a long and important history of glacial aggression, which is largely lost to us. The known history of glaciation practically begins with the time when the ice had

reached its utmost limits. The stages which can be worked out are chiefly those of its retreat and its reduplications. Without neglecting the lost half of the history of glaciation, it is still convenient and customary to speak of the earliest stages hitherto recognised as though they were in reality the oldest.

Subdivisions of the Glacial Formations.—Previous to the last two decades there had been few attempts to apply glacial methods systematically to the subdivision and correlation of the glacial formations of America, and thereby to work out the intimate history of glaciation. In recent years, however, great advances have been made in this direction, and although much remains to be done, the time is perhaps ripe for the tentative presentation of a definite series of subdivisions. American students of the subject are by no means united in their judgment as to the importance of the members of the series thus far distinguished. A portion adopt the general interpretation, long since advanced by Dana and others, which makes the glacial history a simple brief event, and which consequently reduces its subordinate divisions to very low historical rank and comparative unimportance. On the other hand, a large number of workers believe that the glacial formations exhibit ample evidences of great relative differences in age and conditions of accumulation, and that no accurate conception of the history of the Glacial Period is possible without their recognition. Many of these do not insist upon any final judgment as to the precise value of these subdivisions in terms of the geological time-scale, but urge that the subdivisions should be recognised and worked out as a first step towards a satisfactory determination of their chronological importance. In full sympathy with this, it is here proposed to describe the successive overlapping sheets under names chosen to distinguish them. Subsequently, some suggestions as to their time-values may be offered.

The Kansan Formation.—The outermost drift sheet, as already remarked, reaches its maximum southerly extension in Illinois. This apex would form, in many respects, the most appropriate source from which to select a name for the formation. There are, however, in some places, two drift-

sheets separated by a soil-horizon, and it is not yet satisfactorily determined whether this division is widespread and important, or merely local. On this account, it is not thought advisable to draw a name from that region. Perhaps, however, the extension of the ice south-westerly, towards the great arid plains, is equally worthy of emphasis. Certainly this would be so, if we were sure that Labrador was the centre of dispersion. In the teeth of south-westerly winds from what are now hot dry plains, the ice extended 1,600 miles from the centre of radiating striæ in Labrador. In the alternative view the fact is but little less remarkable, for the extremity of the drift in Kansas is about 1,500 miles from the centre of radiating striæ north-west of Hudson Bay. While the formation in Kansas is subordinately divisible, it appears to be an essential unity, and therefore the name *Kansan formation* is selected for present use as a convenient designation of the outermost drift sheet.

This formation consists essentially of a sheet of till, here interpreted as the direct product of land-ice. With it is associated some assorted drift—silt, sand, and gravel. Some of this assorted material lies beneath the till-sheet, some on its surface, and some is interstratified with the till. The amount of the stratified material, however, is relatively small, and the predominance of the till is marked. The amount of valley-drift leading away from the border is notably less than that connected with the later drift-sheets. It is not quite clear how far this is due to original absence and how far to subsequent erosion. In some regions the evidence is clear that the latter was a great factor.

The periphery of this outermost drift-sheet is not usually bordered by any notable ridging of the nature of a terminal moraine. On the contrary, it commonly thins away to a vanishing edge. It is sometimes attended by a belt of scattered erratics, whose limits are not always easily defined. Occasionally, there is a notable thickening at the edge, and, in some regions, a greater depth of drift appears for the first few miles inward than for some distance next succeeding. This would seem to be a slight expression of the law that there was a tendency to deposition under the marginal portion of attenuated ice-sheets, while under the

thicker portion a few miles back from the edge erosion was more pronounced than accumulation. But although this is recognisable by careful scrutiny, the prevailing absence of ridges of drift along the peripheral margin of this outermost sheet, is in strong contrast to the massive terminal moraines by which some of the later drift-sheets are bordered.

The distribution of the Kansan formation has not been fully worked out. The main features, as now interpreted, may be seen by reference to the accompanying map. (Plate XV.) Deposits of this age form the margin of the glacial series across Missouri, and, in part at least, through southern Illinois and Indiana. A narrow, irregular belt outside the terminal moraine in Ohio, and overlapping slightly upon Kentucky in the vicinity of Cincinnati, is referred to this formation, as is also the attenuated border found in north-western Pennsylvania. There is a thin patchy drift outside of the well-known terminal moraine in eastern Pennsylvania and in New Jersey, which is probably also to be referred to the Kansan formation. It may, however, be the equivalent of the next later formation—the East-Iowan.[1]

By reference to the map it will be seen that, while the Kansan formation emerges from beneath the overlapping East-Iowan formation to the extent of 200 miles at the west, it is progressively more and more buried as followed eastward, being almost wholly concealed between central Ohio and New Jersey. It is not known to occur in New England, nor east of it, though remnants of old drift, reported by observers as occurring beneath the prevailing later formations, may perhaps represent it.

North-westward from Kansas all the basal drift of Nebraska, of the western part of Iowa, of the interlobate triangle outside the terminal moraines in south-western Minne-

[1] Some geologists interpret this thin ragged edge of drift outside the terminal moraine as the result either of marginal waters (H. C. Lewis, *Glacial Geology of Great Britain and Ireland*, pp. 51–2), or of a temporary advance of the ice (G. F. Wright, *Ice Age in North America*, 1889, pp. 135–9, 204; also *Amer. Journ. Sci.* March 1893; E. H. Williams, Jun., *Bull. Geol. Soc. Amer.* vol. v. pp. 281–296). In opposition to this view, see R. D. Salisbury, 'Certain Extra-Morainic Drift Phenomena of New Jersey' (*Bull. Geol. Soc. Amer.* 1892, vol. iii.), and 'Report of Progress on the Surface Formations of New Jersey' (*Ann. Rept. State Geologist*, 1892, pp. 60–72); T. C. Chamberlin, 'Diversity of the Glacial Period,' *Amer. Journ. Sci.* March 1893, pp. 184–197.

sota and south-eastern Dakota, and a belt along the Missouri river are referred to it. Probably a large portion of the glacial formation on the plains of Montana, and much of the western portion of that upon the north-western plains of Canada, also occupy the same horizon, but this cannot be stated with any degree of confidence at present. On the north, west, and south-east of the driftless area there are tracts of thin border-drift that are likewise assigned to this stage. The Kansan formation is usually thin, especially in the marginal zone. It is greatly worn in regions where the denuding agents have worked under favourable conditions. In such regions the greater part of the formation has been demolished —mere remnants being left in places where erosion has been carried on at greatest disadvantage. In other regions of flat surface and low declivity the degradation is less marked, and extensive remnants of the original surface-plan have been preserved.

The underlying rock-surface appears to have been only slightly modified by ice-abrasion. Striæ occur in Kansas, Nebraska, south-western and south-eastern Iowa, and southern and western Illinois, but scored surfaces are not abundant. Kames and eskers frequently appear in connection with this formation in southern Wisconsin and north-western Illinois near the driftless region. In the vicinity of Thayer and Afton, in south-western Iowa, there occur buried lenticular masses of gravel that appear to be kames formed on the surface of this deposit and subsequently buried deeply by till belonging to the next higher formation. In general, however, coarse assorted drift is rare in connection with the formation, and valley-trains of gravel are not abundant, except in the Ohio Valley.

The Post-Kansan Interval.—The Kansan formation is overlapped by a later drift-sheet of similar nature, but between them a well-developed soil-horizon occurs. The accumulation of humus and the penetration of weathering are as great, indeed rather greater, than those found to-day on the later drift soils. At many points there are accumulations of peat, logs, sticks, twigs, leaves, stems, roots of grasses, and other vegetal débris.[1] In eastern Iowa Mr. McGee has found vegetal remains in 40 per cent. of the well sections

that cross this horizon, and in 20 per cent. or 25 per cent. of these there is a definite forest-bed or soil-horizon, marking the junction of the two formations.[1] He thinks that these indicate an old soil much thicker and an ancient flora much more luxuriant than those of to-day. In Illinois and Indiana buried vegetal débris occurs so commonly in some districts as to give occasion for popular names, among which the expressive 'Noah's Barnyard' is a general favourite. It is not to be understood, however, that all so named belong to this horizon. These relics of an old surface appear not only under the immediate margin of the overlapping sheet, but fifty miles or more back from the border. Near the margin the ancient soil is naturally less disturbed, although mutilated wood, displaced stumps, and scattered remnants of soil indicate somewhat energetic ice-action. Farther back, the disrupted soils and vegetal beds testify to greater disturbance. As Mr. McGee has well remarked, the frequency of undisturbed vegetal beds is inversely proportional to the intensity of glaciation.

This evidence seems to indicate a very notable period of deglaciation. Opinions differ, however, as to its extent and importance. Some experienced and careful students infer that the interval was at least as long as that involved in the production of the existing soils upon the latest drift, or even longer. Others, at the opposite extreme, urge that the interval need not have been long, and cite the closeness with which vegetation follows the retiring ice in Alaska, New Zealand, and many other alpine glaciers. The vegetation on the border of the Malaspina glacier is especially appealed to. Behind these diverse conclusions there is a radical difference of opinion as to whether arboreal vegetation could hug the border of a continental ice-sheet with the same closeness as it does in the case of the local glaciers referred to, and whether it would follow its retreat with the same promptness. The fauna and flora of the Glacial Period appear to indicate that Arctic species were driven forward beyond the limits of the ice in its lowest reaches, and this is thought by the former class of geologists to indicate that there was a zone of Arctic life bordering the continental ice-sheet. It

[1] *Eleventh Ann. Rept. U. S. Geol. Surv.* p. 487.

becomes, therefore, a matter of special interest to know what is the character of the organic remains entombed in the 'forest-bed' between the two tills. The subject has not, as yet, received as thorough investigation as its importance merits. The organic débris is usually much decomposed, and its proper study requires the skilful manipulation of an expert palæophytologist on the ground. According to Mr. McGee, coniferous wood is by far the most abundant in north-eastern Iowa, but pine, oak, elm, sumac, walnut, ash, hickory, and tamarac have also been recognised. Among the animal remains, *Equus complicatus*, *Lepus sylvaticus*, *Mephiticus mephitica* are among the few species fairly well authenticated as occurring at this horizon. Taken together, these seem sufficient to indicate climatic conditions not much, if at all, more severe than the present. This carries the presumption of a very extensive retreat of the ice, for, whatever may be thought of the possibilities of certain kinds of vegetation following closely on the retreating footsteps of glaciers, it seems scarcely probable that several of the forms named could flourish near a great continental glacier.

Estimates of the extent of the interval have been based upon the erosion of the surface. Among the most specific of these is that of Mr. Hershey,[1] who estimates that the time occupied in the erosion of certain rock-gorges in north-western Illinois was about ten times that which has taken place since the deposit of the newer drift. Assuming the latter to be 7,000 years, in accordance with some recent estimates, he assigns to the work of the interval under consideration 50,000 years as a minimum, and he thinks that twice that time was perhaps not too great for its accomplishment. This is in general accord with the estimate of several experienced geologists based on other and more general data.

The East-Iowan Formation.—Overlapping the Kansan formation, and separated from it by the interval above described, lies a second and similar drift-sheet. This is, in turn, overlapped by a third sheet, presently to be described. We have, therefore, at the surface, only the emerging edge of a sheet imbricated between over- and underlying formations.

[1] Oscar H. Hershey, *Amer. Geol.* Nov. 1893, pp. 314-23.

The East-Iowan till-sheet, like its predecessor, is not usually bordered by any definite terminal moraine. Besides this, it usually graduates vertically and horizontally into silts and clays, apparently the products of fringing waters. On these accounts its limits are not easily worked out, and are as yet only partially known. The extent shown on the accompanying map is quite tentative, and will doubtless need large correction. The designation 'East-Iowan formation' is chosen because it has been most carefully worked out by Mr. McGee in north-eastern Iowa, and there displays its most distinctive features. It is a rather homogeneous, more than usually clayey, sheet of till, freely interspersed with erratics (in part local, and in rather large part foreign), some of which are striated. In Iowa the granitic types predominate. Immense boulders are freely scattered over a portion of the surface. As greenstones prevail in the lower till, there is a petrological as well as a stratigraphical basis for separating the two formations. This difference seems to imply more than a simple recession and re-advance of the ice. It is best explained by a notable change of movement in the Archæan and Algonkian regions at the north.

The thickness of the formation varies from a mere recognisable sheet to 100 ft. or more. Its average in north-eastern Iowa is given by Mr. McGee as 20 ft. This, however, is the marginal portion of the deposit, and is probably too low a figure. It is doubtful, however, whether its thickness in any district reaches an average of 50 ft.

The most notable feature of this drift-sheet is its connection with the main deposits of löss. To forestall misunderstanding, it may be remarked that there are minor deposits of löss associated with other sheets of drift; the formation of löss not being necessarily distinctive of any formation or epoch. The East-Iowan till-sheet is, however, associated with löss of such exceptional extent and nature as to make this epoch especially notable on account of this relationship. As already stated, the till graduates at its edge into löss that spreads far away from its border. It also, in places, passes gradually upwards into a löss mantle. Usually, however, a definite plane separates the till from the löss, and a slight unconformity occurs between the two. The close association of the till and the löss seems to

indicate that it was formed at a time when the drainage about the border of the ice was very slack, so that the silt-burdened waters issuing from it spread themselves widely over the country and gathered reluctantly into great estuary-like rivers, which sluggishly sought the sea. From these slow-moving silt-bearing waters the löss is believed, in the main, to have been deposited. The picture we form is not that of persistent submergence, but of periodical inundations. Perhaps warm rainstorms were the chief agency, since such would not only precipitate large volumes of water upon the ice, but would augment it by the melting due to their warmth. Mr. Gilbert has well remarked that there is no agency by which the warmth of the atmosphere can be so effectively carried to the surface of the ice as by rain.

While this is thought to be the main method by which the löss associated with the East-Iowan formation was produced, the recurrent inundations, by first spreading silt over wide tracts, and then exposing it to the sweep of the winds, may have furnished abundant possibilities for æolian accumulations on adjacent higher lands covered by vegetation. It is quite possible, therefore, that æolian löss may have been formed side by side with aqueous löss. That such wind deposits occur is a view entertained by several students of the phenomena, among them the writer. As yet, however, no satisfactory criteria have been found for distinguishing the two forms of deposition. The accompanying map (Plate XV.) illustrates imperfectly the distribution of the löss and löss-like silts.

Correlation with Coastal Formations.—In the nature of the case there should be fluvial and marine deposits along the Atlantic coast south of the glaciated region equivalent to the glacial formations of the north. Mr. McGee some years ago described and gave the name 'Columbia formation' to a series of such deposits on the Atlantic slope, and has since traced these around into the Mississippi embayment.[1] One member of this is a very coarse bouldery deposit attributed to the agency of floating ice. These deposits he regarded as the equivalents of the early glacial formations, particularly

[1] W. J. McGee, *Amer. Journ. Sci.* vol. xxxv. (May 1888) pp. 367 *et seq.*, and later papers.

the lowest till. He recognised in his early papers, however, two phases, the one connected with the main river systems, the *Fluvial Phase*; the other, spreading over the remainder of the coast plain, the *Interfluvial Phase*; the latter being the older and thinner deposit. Although at first disposed to regard the two formations as essentially continuous and constituting a unit, later studies, particularly in the lower Mississippi region, in conjunction with Professor Salisbury and the present writer, have developed evidences of greater distinctness, and he is disposed to agree with us in tentatively correlating the two phases of the Columbia formation with the Kansan and East-Iowan formations. Recent studies by Mr. Darton have led him to recognise two divisions of the coastal deposits, which he has mapped and described as such, and which he likewise regards as the equivalents of the earlier glacial formations.[1] Until, however, the connections between the southern coastal and the northern glacial deposits are more fully worked out, all correlations must be held quite provisional, and independent local names for the coastal series and for the glacial series will be serviceable.

Interval following the East-Iowan Formation.—Between the East-Iowan formation and the overlapping sheet of till, presently to be described, occurs a second horizon marked by soils, vegetal accumulations, oxidation, ferrugination, erosion, and other indications of a notable interval. These are not traceable so far back beneath the upper formation as in the preceding instance. This may, with good reason, be attributed to the more energetic action of the ice in the succeeding stage, as indicated by the formation of massive terminal moraines, and by other tokens of vigorous action. Nevertheless, even under great depths of morainic débris, soils, beds of peat, and remains of trees are found at many localities. The interval, however, is best shown by the marked differences between the erosion of the preceding and succeeding surfaces. On the one side, the surface is curved into a well-developed erosion topography; on the other, the irregularities natural to glacial deposition have been scarcely modified. On the one side, the drainage is well established and lakes are wanting or extremely rare; on

[1] Article soon to appear in the *Journal of Geology*.

the other, drainage is very imperfect and lakes and undrained basins are numbered by tens of thousands. Broad valleys were cut in the older formation before the newer drift was formed, as is shown by the fact that the outermost terminal moraine of the latter descends into and rises up out of them where their courses cross. There is further evidence of separation in the different conditions of the surface before and after the interval. Just before it, conditions suitable for the deposition of löss prevailed widely over the interior, implying low altitudes and very gentle slopes. Just after it, there was free drainage, and trains of gravel took the place of wide-spreading silts, implying steeper slopes.

It would thus appear that the interval was sufficient to permit a notable change in the configuration and conditions of the land—the development of capacious valleys; the general carving of the surface into an erosion topography; the production of vegetal beds and soils, and the deep penetration of weathering.

The East-Wisconsin Formation.—Overlapping the preceding formation there comes a very complex sheet of drift, characterised by much more pronounced glacial features, among which are massive terminal moraines, not only defining the outer edge of the sheet, but marking various stages of its development, some of which are connected with imbricating overlaps.) For present convenience, all this complex is grouped under a single term—the East-Wisconsin formation—because the grounds for a formal subdivision are not yet sufficiently clear. Eastern Wisconsin is selected as the denominative locality because the formation there takes on a very pronounced development and assumes some of its most striking characteristics.

The formations, taken as a complex whole, may be described as a thick irregular terrane of corrugated till formed by the vigorous action of land-ice, accompanied by free and abundant drainage. The outer border is marked by a distinct terminal moraine, usually one to five miles wide, and from 50 to 300 ft. thick. Back from this border lies a series of similar moraines, some of which are less pronounced, while others are nearly or quite equal to the outermost one. In Illinois, Indiana and Ohio the outermost moraine, together

with one to five of the succeeding ones, constitute a group somewhat distinctly separable from a later group, which embraces from five to seven or more successive terminal moraines. The outermost members of this later group are stronger and more typically developed than the outer group, and are somewhat notably younger and fresher in expression. Moreover, the later set are not entirely concentric with the earlier series, although disposed in the same general fashion. They cross the older group in many places at large angles, indicating a re-adjustment of the ice-currents and a change in the configuration of the border. The interval between the formation of the two groups was probably not equal to the preceding intervals that have been described; indeed, it was probably much inferior to them. It may, however, appear from later studies that it was sufficient to justify the formal recognition of the two groups.

A very notable feature of the East-Wisconsin formation is presented by the loops of its terminal moraines, which indicate strong lobation of the ice-sheet. This lobation was greatly influenced, indeed, in the main, controlled by the broad open valleys of the region. Narrow valleys, though deep, appear to have had little effect, but broad open basins, especially those whose axes lay in the general direction of ice-movement, and which reached considerable distances back from the margin, seem to have been very effective. The accompanying map presents to the eye something of the extent and nature of this lobation (Plate XV.). It is in connection with this formation that the drumlins, the kames, and eskers have their most pronounced development. Along the outer side, not only of the outermost moraines, but of some of the later ones, there are extensive aprons of overwash, and from these there gather into the valleys great trains of gravelly drift. These phenomena indicate a free and vigorous drainage in strong contrast to the slack drainage implied by the löss and silts of the preceding formation. From this it is inferred that the altitude and slope of the land were at least as great as at present; perhaps at the maximum of vigorous action somewhat greater. The fluvial deposits do not, however, imply a great altitude. On the surface of this formation, in favourable localities, there

are extensive sand-plains indicating vigorous drainage during the recessional stages of the ice-sheet. These are particularly abundant in northern Minnesota, Wisconsin, Michigan, Ontario, and not infrequent in the Eastern States.

Lacustrine Formations.—As the ice-edge drew back into the basins of the great lakes, water accumulated abundantly between it and the water parting, and sought favourable points of discharge into the Mississippi basin. These fringing lakes made deposits of greater or less amount according to the extent and the duration of the ponded waters. With the progress of events, a very complicated series of such lakes were formed, changing their outlines and outlets with the changing attitudes of the ice and the opportunities thus given for coalescence among themselves. The shifting series may be regarded as continuing until the drainage settled down into its present form, although it is not clear, as will be seen later, that the series was altogether uninterrupted. The deposits consist of stratified clays, sands, and gravels, bordered by beach-lines when the extent of the water-body and its duration were sufficient for their development. Associated with the stratified material are clays somewhat abundantly charged with glaciated erratics, which have sometimes been interpreted as glacio-natant deposits, and sometimes as the products of a re-advance of the ice-sheet. It is very probable that both interpretations are correct in individual instances, for it is more than likely that both classes of formations were produced. All the existing great lakes between the United States and Canada, and probably all the great lakes of north-western Canada, are bordered by these deposits, which bear witness to their former extension. The greatest of these former expansions has been called by Mr. Upham, who has worked out the phenomena in great detail, Lake Agassiz. It embraces the present Winnebago, Winnepegosis, and Rainey lakes, and a large additional tract in Manitoba, Minnesota, and Dakota, constituting the great plain of the Red River of the north.

The Toronto Fossiliferous Beds.—On the northern shore of Lake Ontario, near Toronto, occur stratified beds overlain by till which possess peculiar interest from the fact that they contain fossils that indicate an important interglacial

episode. As long ago as 1877, Dr. Hinde described a magnificent section along the face of Scarborough Heights nine and a half miles in length and 290 ft. in extreme height.[1] The bottom of the series is not there shown, but at Garrison Common and Humber Bay, twelve miles distant, there appears at the base of the drift, resting upon a striated floor of palæozoic rock, a typical bed of till 25 ft. in thickness, overlain by fossiliferous beds identical in nature with those at the base of the Scarborough section. The fossiliferous beds along the River Don, to be described in the sequel, lie between these localities and strengthen the correlation. The lowest exposed member of the Scarborough series consists of 140 ft. of fossiliferous clays and sands free from pebbles and boulders, well stratified, and bearing plant remains from base to summit, together with some animal remains. Among these the following were identified: the diatoms *Navicula*, *Stauroneis*, and *Pinnularia*, a species of *Chara*, the mosses *Bryum*, *Fontinalis*, *Hypnum commutatum*, *Hypnum revolvens* (?), and an undetermined species of *Hypnum*, spores of *Lycopodiaceæ*, wood of pine or cedar, portions of leaves of rush and other plants, and a variety of seeds; two or three species of *Cypris*, a wing-case of a carabid, and the gasteropods *Zonites* (?) and *Planorbis*. Upon these fossil-bearing beds lie from 10 to 70 ft. of till, overlain by 90 ft. of laminated clay and sand in which no fossils were found. These beds, in turn, are overlain by 30 ft. of till, while this, again, is surmounted by 50 ft. of stratified sands and gravel.

Interest has very recently been reawakened in these remarkable formations through the finding of very significant fossils in similar beds on the River Don, at Toronto, by Messrs. Coleman, Townsend, and others. The fossiliferous beds are underlain and overlain by till. The higher part of the Scarborough section is unrepresented, apparently on account of erosion. Among the fossils, Mr. Penhallow has identified the following plants :—*Taxus baccata*, var. *Canadensis*, *Asimina triloba*, *Ulmus racemosa*, *Acer pleistocenicum* (a new species), *Fraxinus quadrangulata*, and *Quercus obtusi-*

[1] 'The Glacial and Interglacial Strata of Scarboro' Heights and other Localities near Toronto, Ontario' (*Can. Journ.* April 1877).

loba. The yew, the elm, and the oak are now found in Canada, and range a few degrees farther north. The ash occurs in the southernmost part of Canada, but its range is southerly. The papaw is known to occur north of Lake Erie (Macoun), but apparently not as far north as Toronto. Its range is decidedly southern. It appears, therefore, that while some members of the group range a few degrees farther north, the group as a whole belongs to a more southerly latitude. The new species of maple is interesting as suggesting the probable extinction of a species by the later glaciation.

The following is a list of the molluscan forms, with notes on distribution, on the authority of Dr. Dall and Mr. Simpson:[1] *Unio phaseolus* (found in the Mississippi drainage-area), *U. occidens* (probably ubiquitous), *U. pustulosus* (Mississippi drainage-area, Wisconsin, and Minnesota); *U. schoolcraftii* (Atlantic drainage, Lakes Erie and Michigan); *U. undulatus* (ubiquitous); *U. rectus* (ubiquitous); *U. trigonus* (Mississippi drainage); *U. solidus* (Mississippi drainage); *U. clavus* (Mississippi drainage); *Sphærium striatinum* (ubiquitous); *Pleurocera subulare* (St. Lawrence drainage); *P. elevatum* (Mississippi drainage); *P. sp. indet.*, *P. pallidum* (one specimen, doubtful); *Valvata sincera*, var. (ubiquitous).

The significance of this fauna lies in the fact that the present unios of the Mississippi and Atlantic basins are, except a few ubiquitous species, in a high degree distinct. But here we have a group, several species of which are now exclusively Mississippian, flourishing on the farther side of the middle St. Lawrence basin. This seems to imply that the molluscs of the Mississippi Valley migrated across the divide into the St. Lawrence basin, following the retreat of the ice, and penetrated as far north-easterly as the Ontarian region at least, where they flourished abundantly for a time, until subsequently an invasion of ice drove them out, and buried the deposits containing their relics. The drainage conditions were doubtless the most favourable for such migration during that depressed stage which was marked by

[1] *Proc. Nat. Mus.* xvi. 1893. I am personally indebted to Dr. Dall for suggestions respecting the significance of this remarkable fauna. T. C. C.

the abundant lössic accumulations associated with the East-Iowan formation. The conditions of depression which characterised the deposition of the löss are in keeping with the fact that the Toronto fossils occur as high as 140 ft. above the present surface of Lake Ontario. On the supposition, therefore, that the Toronto beds are of later date than the East-Iowan formation, it would follow that the subsequent ice-invasion, which produced the East-Wisconsin formation, would necessarily have forced the fauna completely out of the St. Lawrence basin. An objection to this hypothesis, perhaps, lies in the fact that the fossiliferous beds are about 100 miles back from the limit of the ice-invasion, and it may appear remarkable that they should have escaped destruction. The Scarborough section, however, does show that much has been lost. The force of the objection is further weakened somewhat by observing that Toronto is nearly opposite the angle of the drift border in New York, and hence may have lain within an interlobate tract rather than in a main channel of the ice-movement. A still greater objection would be encountered if the fossiliferous beds were referred to the earlier interval between the East-Iowan and Kansan formations. As an alternative hypothesis, the till under the fossiliferous beds might be correlated with the East-Wisconsin formation. In this case the molluscs must have been driven out by a still later ice-invasion, which may be supposed to have formed the two upper beds of till (seventy feet and thirty feet respectively, at Scarborough Heights), but which, as it did not reach much beyond Toronto, did less destructive work on the fossiliferous beds. The limit of this invasion might perhaps be found in some one of the terminal moraines which have been imperfectly worked out west and south of Lake Ontario. This hypothesis escapes one difficulty to meet another in the present absence of these molluscs from the southern and western borders of the upper St. Lawrence basin. For although the great lakes might have been much affected by a partial re-encroachment of the ice, the molluscs might well have survived in the southern tributaries, unless the severity of Arctic conditions was too great for them. If this last be the correct interpretation, there would seem to be sufficient ground for recognising the deposits above the

fossiliferous beds as constituting a distinct formation, since they would be separated from the East-Wisconsin formation by 140 ft. of fossiliferous beds, marking climatic and physical changes of very considerable importance. This would also make the early lacustrine history of the St. Lawrence basin distinctly separate from its later history, of which independent evidence seems to be wanting. A comparison between the relative amount of erosion suffered by the drift formations north of the St. Lawrence basin, and the Wisconsin formation south of it, does not seem to furnish grounds for supposing these to be of greatly different ages. Both are alike fresh in surface aspect. On the whole, therefore, it seems best for the present to correlate the fossiliferous beds of Toronto with the interval preceding the East-Wisconsin formation, and to regard the two overlying beds of till as perhaps representing the two divisions of the East-Wisconsin formation before referred to.

The facies of the fauna and flora of the Toronto beds points to milder climatic conditions than the present. The molluscan fauna would be appropriate to central Illinois, the flora to southern Ohio. The eastern migration of the Mississippian molluscs is very remarkable, and the presence of a new species of maple helps to make up a very significant combination. The thickness of the fossiliferous beds—140 ft.—their freedom from coarse detritus and from all evidence of contemporaneous ice-action, and their extremely fine lamination, in part—twenty layers to the inch—give them great importance as an interglacial formation.

The Champlain Deposits.—After the retreat of the ice from the St. Lawrence valley, the sea extended up its lower portion to a distance as yet unascertained. It is known to have deeply submerged Montreal, reaching 560 feet above present sea-level,[1] and to have occupied the Champlain basin, for abundant marine fossils are found there. In the great lake region, however, no marine fossils have yet been detected. It seems highly probably that brackish, if not saline, waters extended into these basins, for the marine crustacean *Mysis* has been found living in Lake Michigan,

[1] Sir William Dawson, *The Canadian Ice Age*, p. 201.

and it is most reasonable to suppose that it underwent adaptation by gradual transition from saline to brackish, and from brackish to fresh waters.

Around the coast of the south-eastern Provinces, and on the south coast of Maine, there are marine deposits that have usually been referred to the Champlain epoch. While this is the more probable interpretation, it is not beyond question, since there is evidence that the marine deposits on the coast of Maine were contemporaneous with the glaciation of that region,[1] while the marine deposits of the St. Lawrence basin were only formed after the ice had evacuated it, and, unless the view of those who maintain the local character of the glaciation of eastern New England be correct in the fullest sense, the two events were not strictly contemporaneous, though they may have been closely successive.

Chronological Interpretations.—We have now reviewed briefly the leading members of the glacial series regarded simply as natural divisions that indicate the succession of events. It remains to consider them from a somewhat more general and chronological point of view. How much do these divisions signify? Do they indicate merely marginal fluctuations of the ice-sheet measured by a few scores of miles or a few hundreds of years, or do they mean a succession of profound fluctuations measured by hundreds of miles and thousands of years; or do they signify entirely distinct glaciations separated by complete returns to genial climatic conditions? Do some of them have a significance of one order, and others of a different order?

We have no brief terms in established usage that designate precisely these grades of interpretations. The American use of the terms period and epoch is not precisely the same as the English or the Continental usage, nor do all Americans employ them in the same sense. Beside this, all such chronological terms commonly cover more ground when applied to earlier or little known formations than to later or familiar ones; the law being that what is near to us and important is magnified. Under this recognised practice, we are justified in regarding as epochs and periods important phases of events so near and so vital to us as those of

[1] George H. Stone, *Journ. Geol.* vol. i. No. 3, 1893, pp. 246–254.

the Ice Age, even though they might sink to lower grades were they thrown into the dim perspective of earlier geological ages. There is, however, need of some definite idea of what is meant by such terms, if adopted. Our best standard is the present period. If the ice should again overwhelm one-half of North America, it would doubtless be regarded as a new glacial period, not as an epoch of the old one. If the Ice Age consisted of distinct glaciations separated by climatic conditions as genial as those of to-day, they might as properly be called periods as epochs of glaciation. If the intervals of ice retreat, whether they amounted to complete disappearances or not, were comparable to the postglacial period in duration, in the amount of erosion, weathering, soil production, vegetal accumulation, orographic movement, or other work done, or, in the geniality of their climate or the character of their life, they are surely entitled to be recognised as marking epochs. If the intervals fall notably short of this, it is doubtless best to regard them as marking episodes, rather than epochs. The need for recognising them would still remain, however, if we are to decipher and delineate the intimate history of the Ice Age.

The facts which have been given, though too imperfectly set forth, seem to show that the work of erosion effected during one or two of the intervals at least was greater than that accomplished since the last retreat of the ice. In like manner the organic evidence relative to one or two of the intervals, though lacking much in fulness, points towards climatic conditions comparable to the present. The main problem of chronological interpretation, therefore, appears to lie between the second and third interpretations above suggested, although, as previously indicated, there are prominent glacialists who dissent from this view, and maintain that fluctuations of the ice were narrowly limited in extent and in duration, and that the whole Glacial Period was brief. To the writer of this outline, the present problem does not embrace the question of brevity or simplicity, but is limited to this: Was the glaciation interrupted by protracted epochs of retreat without total disappearance, or were there periods of complete deglaciation? Reference is here made only to the disappearance of ice from the plains of the north-

eastern mainland. No one probably doubts the persistence of glaciation on the heights of the Cordilleras or in Greenland.

A secondary question bears upon the number and value of the intervals. The two most important seem clearly to be that between the Kansan and the East-Iowan formations and that between the East-Iowan and the East-Wisconsin formations. The intervals separating the subdivisions of the East-Wisconsin formation appear to be less important, and from the relative freshness of the surface of this formation it seems unlikely that any later episodes that may be developed in the working out of the more central portion of the drift field will be found very protracted. If the Toronto fossiliferous beds belong to the interval preceding the East-Wisconsin formation, they give high rank to it when taken in connection with the physical evidence before cited. If they fall later, they add a third notable interglacial epoch.

Between the chief intervals it is not easy to decide, from present evidence, which is most important, or whether both should take equal rank. There has been a growing disposition among field workers to recognise three glacial epochs, and in many respects this furnishes the most satisfactory interpretation of present data drawn from the glacial deposits themselves.

There are, however, some outside evidences in favour of the bipartite view. The most important is that found in the ancient lake deposits of the Great Basin region by Messrs. Gilbert,[1] Russell, and others. The Bonneville and Lahontan phenomena indicate two periods of humidity separated by one of aridity. The first period of humidity was the longer and more gradual in development, the last was the shorter and more intense. This is in close harmony with earlier and later glaciations as first grouped below. So far, there seems to be forthcoming no evidence of more than two humid periods. The last of these has been shown to be closely associated with the last extension of glaciation on the Wasatch and Sierra Nevada mountains, and so the presumption is strong that these periods of humidity correspond to the stages of pleistocene glaciation. This lends strong

[1] G. K. Gilbert, *Mon. U. S. Geol. Surv.*, 'Lake Bonneville,' 1890, pp. 214–316; I. C. Russell, *ibid.*, 'Lake Lahontan,' 1885, pp. 250–254.

support to the view that there were two predominant epochs or periods of glaciation, and that the remaining divisions are dependencies of these to be ranked as episodes or epochs.

Along the rivers leading away from the glaciated area, there are trains of valley-drift corresponding to the stages of glaciation. The earlier of these were greatly eroded before the later were formed. In most instances, the trenches in which the later trains were deposited were cut out of the earlier deposits. These trenches are generally much broader and deeper than those which the rivers have made since the Glacial Period closed. The independent estimates of several experienced glacialists make the erosion of the earlier deposits not simply two or three times that of the later, but ten or twelve times, or more. Present evidence seems to indicate two chief systems of valley-drift separated by one chief interval of erosion. A more complete working out of these systems may, however, show greater complexity.

The following groupings represent different interpretations entertained by experienced field workers who believe in the differentiation of the drift series. They are formulated in the nomenclature of this sketch. All who give preference to one grouping are, so far as we are aware, favourably disposed to the others, recognising that present evidence, while it looks in the directions indicated by these groups, is not altogether decisive between them.

First Grouping on a Twofold Basis.

1. Concealed under-series (theoretical)	Unknown	
2. Kansan stage of glaciation	Early glacial epoch	Glacial Period
3. First interval of deglaciation		
4. East-Iowan stage of glaciation		
5. Second interval of deglaciation	Chief interglacial epoch	
6. East-Wisconsin stage of glaciation	Later glacial epoch	
7. Retreatal oscillations of undetermined importance		

Second Grouping on a Twofold Basis.

1. Concealed under-series (theoretical)	Unknown	
2. Kansan stage of glaciation	Early glacial epoch	Glacial Period
3. First interval of deglaciation	Chief interglacial epoch	
4. East-Iowan stage of glaciation	Later glacial epoch	
5. Second interval of deglaciation		
6. East-Wisconsin stage of glaciation		
7. Retreatal oscillations of undetermined importance		

Grouping on a Threefold Basis.

1. Concealed under-series (theoretical) . .	Unknown	
2. Kansan stage of glaciation . . .	First (represented) glacial epoch	Glacial Period
3. First interval of deglaciation . . .	First interglacial epoch	
4. East-Iowan stage of glaciation . . .	Second glacial epoch	
5. Second interval of deglaciation . . .	Second interglacial epoch	
6. East-Wisconsin stage of glaciation . . ; 7. Later oscillations of undetermined importance	Third glacial epoch, embracing possibly a fourth glacial epoch	

[Until American geologists are agreed as to which of the three groupings indicated by Professor Chamberlin gives the most reasonable interpretation of the evidence, detailed correlation of the glacial succession in Europe and North America need not be attempted. It is obvious, however, that the general conclusions arrived at by Mr. Chamberlin harmonise well with the results obtained in Europe. In both continents the glacial accumulations yield evidence of climatic oscillations. Again, in North America as in our own continent the epoch of maximum glaciation occurred at an early stage in the period—after which the succeeding ice-sheets declined in importance. The grouping of American glacial history on a threefold basis as given above runs so closely parallel to our own succession that I cannot avoid pointing this out. Patches of 'old drift,' as we have learned, occur here and there buried under the accumulations of the Kansan stage, which may possibly occupy the horizon of our Weybourn Crag and the ground-moraine of the earliest great Baltic glacier. But this, of course, it is obviously impossible to prove. Leaving our First Glacial Epoch out of account, and coming to the records of the next succeeding cold stage in the European succession, we are on surer ground. This Second Glacial Epoch is that of the maximum glaciation, and we need not hesitate to correlate it with the Kansan stage of Mr. Chamberlin's classification. His description of the Kansan formation indeed applies exactly to the 'lower diluvium' of Central Europe. In both continents terminal moraines are of infrequent occurrence along the margin of the greatest of the drift-sheets. The East-Iowan stage of glaciation answers very well to our

Third Glacial Epoch. In America the formation is not bordered by conspicuous terminal moraines, and the same is largely the case with the corresponding ‘diluvium’ in the Plains of Europe. The most marked feature of the East-Wisconsin formation is the enormous development of terminal moraines. Now, it is most notable that the same is the case with what I take to be the corresponding deposits in Europe. The great terminal moraines of the Baltic Ridge exactly recalled to me the similar accumulations which I had seen in Long Island, New Jersey, Pennsylvania, Ohio, Wisconsin, and Minnesota. The resemblances thus pointed out between those three successive glacial stages as developed in North America and Europe respectively can hardly be mere coincidences. Professor Chamberlin thinks it possible that the East-Wisconsin stage of glaciation may have been succeeded by yet another glacial epoch, marked by a second series of large terminal moraines. If this should eventually prove to be the case we should have in North America a parallel to Dr. Hansen's ‘epiglacial epoch’—which was characterised, it may be remembered, by the appearance of large glaciers in the mountain-valleys of Norway. These glaciers I take to be the equivalents of the valley-glaciers in Scotland which here and there reached the sea.—J. G.]

CHAPTER XLIII.

CAUSE OF THE CLIMATIC AND GEOGRAPHICAL CHANGES OF THE GLACIAL PERIOD.

Physical conditions of Glacial Period—General depression of snow-line—Inter-glacial climate—Geographical changes—Earth-movements—Connection between glaciation and submergence—Views of Croll, Penck, Jamieson, Chamberlin, Drygalski, &c.—Origin of climatic conditions of Glacial Period—Views of Evans, Lyell, and others—Hypothesis of earth-movements—Brückner on climatic fluctuations of recent times—Croll's theory of climatic changes—Views of Sir R. Ball—Correspondence of the geological evidence with the requirements of the astronomical theory—Objections considered—Conclusion.

HAVING now passed in review the geological evidence as to the climatic and geographical changes of the Glacial Period, we have finally to consider how those changes originated. It would serve no useful purpose to attempt any detailed examination of the various hypotheses which have been advanced to account for the Glacial Period. Most of these were framed at a time when our knowledge of the facts was somewhat crude and rudimentary, and therefore call for no more than a passing reference. The reader who has accompanied me so far will, I hope, have a clear notion of the salient phenomena that call for theoretical explanation, but it may not be amiss to summarise here, as briefly as may be, the leading features of the evidence.

Let us then consider first the conditions that obtained during the cold or *glacial phase* of the period. We find that in Europe a great ice-sheet covered the northern and north-western regions, while the mountain-tracts supported extensive snow-fields and glaciers. We note, further, that these glacial phenomena were developed more powerfully in the west than in the east, as a glance at the map (Plate XIII.) will show. The ratio of precipitation in glacial times was obviously analogous to the conditions that now obtain. Snow-fields and ice gathered most abundantly in those

regions which in our day enjoy the largest rainfall. In what are now the drier parts of our continent less snow fell and few or no glaciers of importance came into existence. Passing into Asia the same facts confront us—glaciers were restricted to the lofty table-lands and plateaux—the broad low-grounds of Siberia supported no ice-sheet like that of North-western Europe. In North America, in like manner, the former distribution of snow and ice was in strict accord with existing conditions. What are now dry regions were formerly regions of limited snow-fall. Further, we may observe that North America has been more extensively glaciated than Northern Europe, just as in our own days Greenland shows more snow and ice than Scandinavia. The only glaciers and ice-sheets that now exist in northern latitudes are confined to formerly glaciated areas. There can be no doubt, in short, that the conditions of glacial times bore an intimate relation to those that now obtain. 'Durchweg bestand sie,' as Professor Brückner remarks, 'in einer Potenzierung der jetzigen Vergletscherung.' But although the ratio of precipitation appears to have been similar, the amount was greater. Everywhere in the non-glaciated tracts we have evidence of a more copious rainfall. Pluvial conditions in the southern were contemporaneous with glacial conditions in the northern latitudes of our hemisphere. From a full consideration of the facts, therefore, we are justified in concluding that a general displacement of climatic zones took place in glacial times—and that this change was accompanied by increased precipitation.

Let us now note some suggestive facts connected with the glacial phase in Europe. The lowering of the temperature is evinced not only by the widespread phenomena of glaciation, but by the former presence in our temperate latitudes of a northern flora and fauna. Arctic conditions then reigned in Middle Europe, and the climate of the Mediterranean lands was colder and wetter than at present. The western shores of the Continent were washed by chill currents, as is shown by the arctic shell-beds of our own lands and the appearance of northern species in the Pleistocene deposits of Italy. If we turn to North America,

similar facts are apparent--an arctic current laved the coasts of Canada and New England. If any Gulf-stream flowed into the North Atlantic during the climax of the glacial phase, it must have been of inconsiderable importance. All the evidence we have would seem to suggest that the prevalent surface-currents came at that time from the north, and doubtless it was floating-ice carried by these currents that brought erratics to the Azores.

The climatic conditions of the *interglacial phase* differed greatly from those we have just been considering. At the culmination of a genial epoch Europe was in the enjoyment of a singularly equable climate—the summers and winters of our temperate latitudes being much less strongly contrasted than at present. We must go back to the Pliocene period to find a climate comparable to that of interglacial times. Summer was not so hot and dry as now in Middle and Southern Europe, while winter was certainly much more clement. This is shown by the peculiar distribution of plants and animals, which, as we have seen, differed very considerably from the present. An insular or oceanic climate prevailed over the Continent, extending even into the heart of Russia. When we turn from the evidence supplied by the terrestrial floras and faunas of interglacial times to that furnished by the contemporaneous marine accumulations, we meet with similar proofs of wide-spread equable conditions. Northern and boreal species disappeared from the Mediterranean, while the shores of Italy were visited by a molluscan fauna—the general facies of which is indicative of warmer waters than the present. Southern forms then lived in the Mediterranean which have since vanished from that sea. So again in the shell-beds of Britain and Scandinavia we meet with many species that no longer flourish in these latitudes. And the same is the case on the other side of the Atlantic. In many of the raised-beaches of New England and Nova Scotia occur southern species which do not now frequent those shores. And a similar tale is told by certain shell-beds in Greenland and Spitzbergen. The occurrence of genuine colonies of southern forms in the Gulf of St. Lawrence and off the coast of Nova Scotia, and the similar colonies discovered off the coasts of Iceland, Ireland, the Outer Hebrides,

and Shetland, afford evidence which is quite in keeping with that supplied by the raised-beaches. Obviously all the facts point to the same conclusion—that formerly the North Atlantic in those latitudes had a higher temperature.[1] And this naturally leads to the inference that during the interglacial phase the dominant set of the currents was from south to north—a much greater body of warm water flowing into northern latitudes than is now the case.

Here, then, we arrive at the interesting and suggestive conclusion that the glacial phase was characterised by a general drift of cold water towards the south, and the interglacial phase by a prevalent set of warm waters in the opposite direction.

I have spoken of a glacial and an interglacial phase, but it will be remembered that these phases frequently alternated. As I have tried to show, we have evidence in Europe of six cold epochs with intervening epochs of genial conditions. And I would remind the reader that these several cold and genial stages were not all equally extreme and equally mild. The climax of glacial cold was reached not in the first but in the second stage, and after that each successive glacial epoch declined in importance. So it was also with the interglacial stages. The first, characterised by the presence of *Elephas meridionalis*, would appear to have been the most genial and equable—each succeeding epoch approaching nearer and nearer to existing conditions.

It may be as well to remark that in speaking of the glacial and interglacial stages I have in view at present the character of each at its climax. We are not to suppose, however, that there was any sudden and abrupt change from a cold to a genial epoch. The evidence distinctly points to the contrary, and if there could have been preserved, in one particular place, a full and complete record of all the phases of the Glacial Period, we should doubtless have found that each stage merged gradually into the other. It would have been impossible, in short, to draw a hard and fast line between any two stages.

Let us now briefly review the evidence as to the geo-

[1] The reader will find the evidence relating to this part of my subject set forth in *Prehistoric Europe*, chapter xxi.

graphical changes of the Pleistocene period—the changes in the relative level of land and sea. In the first place, then, we find that submergence was characteristic rather of the glacial than the interglacial phase. Most of the marine deposits of the Pleistocene age bear witness to cold climatic conditions. Such are the arctic shell-beds of Europe and North America. The submergence that now and again accompanied the genial interglacial phase was neither so profound nor so extensive. In considering the question of such changes it is obvious that we must not confound the oscillations of one cold epoch with those of another similar stage. The changes of level of each epoch must be considered separately. Now the particular submergence concerning which we have the fullest evidence is that which took place in Europe and Asia during the fourth glacial epoch. At that time the depression in Scotland did not exceed 130 ft. In Scandinavia the submergence was greater, reaching as much as 880 ft. In Northern Russia the marine deposits of this stage have been traced to a height of 600 ft., and to a less height in Northern Siberia. The submergence, therefore, affected a wide area, but it varied remarkably. There is nothing to show, for example, that the coast-lands of England and Ireland were drowned to the same extent as those of Scotland. Similarly, in Scandinavia, Southern Sweden was not affected. The only inference we can draw from such facts is that the changes of level were due, not to a general rising of the sea upon the land, but to unequal deformation of the earth's crust. The records of that epoch of submergence are the fullest simply because the areas overflowed by the sea at the time have not since been subjected to extensive glaciation. It is otherwise with the marine accumulations of earlier stages. There is clear evidence, for example, that considerable submergence supervened in the British area after the disappearance of the ice-sheet of maximum glaciation and before the advent of its successor. And similar evidence of depression is obtained from the contemporaneous deposits of the Baltic coast-lands. But the subsequent appearance of another great ice-sheet in all those regions necessarily led to the destruction of marine accumulations, and, in some places, to their concealment under

glacial deposits. Sufficient evidence, however, remains to show that the depression was due, like that of the fourth glacial epoch, to deformation of the crust. Turning now to North America, we meet with proofs of submergence in a cold sea from the latitude of New York up to Greenland. Northern shells are found at successively higher levels as we follow the coast-line northwards. Thus they occur at a height of 200 ft. in New England, of 560 ft. at Montreal, of 1,000 to 1,500 ft. in Labrador, and of 1,000 to 2,000 ft. in the Arctic regions. We do not know, however, whether all these raised-beaches, &c., are to be assigned to one and the same glacial stage. Probably they are not. But the researches of Professor Spencer, Mr. Gilbert, Mr. Upham, and others, leave us in no doubt that unequal movements of the crust characterised the Glacial Period. Here, however, it is only necessary to point out that most of the Pleistocene marine deposits of North America belong to the glacial phase of the period.

Marine deposits indicative of genial conditions are of less frequent occurrence than those containing arctic and northern forms. The inference from this would thus seem to be that depression or submergence was more characteristic of the glacial than of the interglacial phase. Many facts, indeed, point to the conclusion that a wide extension of land in northern regions has often co-existed with genial climatic conditions. Thus, to go no farther back than the warm Miocene and Oligocene periods, we have good reason to believe that land-connection then obtained between Europe and North America in the general direction of the Færöe-Icelandic bank. We may take note also of the fact that fiords or sea-lochs are a common geographical feature of north temperate and arctic regions. Now these fiords are simply submerged or partially submerged land-valleys, which came into existence long before the Glacial Period. The fiord-valleys of Norway and Scotland have been excavated by running water at a time when the land stood some 2,000 to 3,000 ft. higher than now. And the same may be said of the fiord-valleys of North America and Greenland. No doubt all the fiords have been more or less profoundly modified by subsequent glacial action—but the fact remains

that they existed as river-valleys, reaching far back into the heart of the land, long before the advent of the Pleistocene period. If such be the case, then it is obvious that during the excavation of those valleys the climatic conditions of high northern regions could not have been so cold as they are in our own day. In short, there is no reason to doubt that warm and genial conditions have obtained at times in the higher latitudes of the North Atlantic, when the adjacent regions stood at a relatively greater elevation, and when wide areas of what is now sea-bottom existed as dry land.

Let us confine our attention, however, to those oscillations of level which took place during the Pleistocene period. We have already glanced at the evidence of submergence during the glacial phase of that period, and we must now consider the geographical conditions that marked the interglacial phase. For this purpose we naturally turn to that interglacial stage of which the records are the fullest and most complete—the stage, namely, that followed the disappearance of the last great Baltic glacier, and of the large district glaciers of the British area. It will be remembered that the dissolution of the great Baltic glacier and of the district glaciers of Scotland was accompanied by an irregular movement of depression and the consequent transgression of considerable areas by arctic waters—the Yoldia Sea of Scandinavian geologists. That movement, as we have seen, was succeeded by one in the opposite direction, when the sea retreated and the climate gradually became warmer. The climax of this stage was reached when the British Islands formed part of the Continent and the North Sea practically disappeared, and when luxuriant forests spread far north beyond their present range and reached elevations on the land where nowadays they do not grow. I have elsewhere given my reasons for believing that at this time a land-connection obtained between Europe, the Færöe Islands, and Iceland, and perhaps even Greenland.[1] This inference is based chiefly on the character of the flora of those regions. It is well known that the assemblage of plants in the Færöe Islands, Iceland, and Greenland is essentially Scandinavian, and could hardly have immigrated except by a land-passage.

[1] *Prehistoric Europe*, chap. xxi.

Having studied the glacial phenomena of the Færöe Islands and Iceland, I cannot believe that these islands supported any flora during glacial times. Their plants have almost certainly been introduced since the lands were last overwhelmed by ice. And the same may be said of Greenland. If it be suggested that the flora might have been drifted by ocean-currents, I may point out that at present the drift is from the south-west, and that the flora, if it came by sea, ought to have had a prevalent North American character. During the glacial stage in question the general drift of the surface-waters was no doubt southwards, but then it must be remembered that Norway at that time was drowned in ice, and that the Færöe Islands and Iceland were similarly covered—so that under such conditions immigration by sea is hardly likely to have taken place. We seem, then, shut up to the conclusion that the Scandinavian flora migrated to the Færöe Islands, Iceland, and Greenland by a land-passage after the disappearance of extreme glacial conditions. In a word, the migration most probably took place during the interglacial stage that followed after the close of the fourth glacial epoch. Be this, however, as it may, it is quite certain that this interglacial stage was characterised, not only by genial climatic conditions, but by a vast extension of the northern lands—not only in the region of the North Atlantic, but in Northern Asia, which appears to have been then united across Behring Strait with America. We note, further, that while those genial conditions continued, a movement of depression set in—the records of which are seen, as already mentioned, in the deposits of the Littorina Sea of Scandinavia, in some of the raised-beaches of Scotland, and in certain low-level accumulations on the opposite coasts of the Atlantic.

Of the geographical conditions of earlier interglacial times our knowledge is less complete. There is evidence, however, to show that each of those stages was characterised by the appearance of a wider land-surface in North-west Europe than now obtains. Witness the conditions that marked the stage of the Pliocene 'forest-bed,' when Britain was joined to the Continent and the southern half of the North Sea existed as dry land. Again, we have reason to

believe that our islands similarly formed part of the Continent during the *Elephas antiquus* stage—the genial stage that intervened between the phase of maximum glaciation and the succeeding or third glacial epoch. I make no special reference to the geographical conditions of the Mediterranean area further than to point out that one or more land-passages seem to have existed now and again between Europe and North Africa, across which the Pleistocene mammals wandered to and fro.

To sum up. It is beyond dispute that in all those regions in which the superficial accumulations have been most carefully studied abundant evidence is forthcoming to show that the Glacial Period was characterised not only by great climatic changes, but by marked mutations in the relative level of land and sea—the climatic and geographical changes becoming less and less pronounced as the period drew to a close.

As the climatic changes of the Glacial Period have been thought by some geologists to owe their origin to the earth-movements referred to, it will conduce to clearness if I treat of the latter first. Various and conflicting views have been advanced in regard to these. While some, as just mentioned, maintain that the climatic vicissitudes were caused by oscillations of the crust, others have held that it was quite the other way—that the changes in sea-level were due to the alternate appearance and disappearance of the great snow-fields and ice-coverings. The late Dr. Croll supported the view that the abnormal accumulation of snow and ice in the higher latitudes of our hemisphere sufficed to disturb the earth's centre of gravity, and thus caused a rise of the sea-level, increasing in extent from low latitudes towards the pole. This theory has also been considered by several physicists—Lord Kelvin, Archdeacon Pratt, Mr. D. D. Heath, and Rev. O. Fisher—and the general impression left by the discussion is, that we have in this particular view a *vera causa* of changes of sea-level. As Croll believed that glacial epochs in one hemisphere coincided with interglacial epochs in the other, and *vice versa*, it was obvious, according to him, that a rise of sea-level on a glaciated hemisphere must have coincided with a sinking of sea-level on the non-glaciated

hemisphere. From the point of view of the geologist there is something to be said in favour of this theory. Thus, it certainly harmonises so far with the fact that submergence was markedly characteristic of glacial conditions, while emergence was just as characteristic of genial interglacial times. But, even if we admit the truth of the theory, it yet does not explain other phenomena—for later detailed observations have shown that many of the oscillations were certainly the result of deformation of the crust. Croll, himself, quite recognised this, but pointed out that, as elevations and depressions of the land have occurred in all ages, they doubtless took place also during the Glacial Period.[1] A stronger objection to Croll's theory, however, has been stated by Mr. Jamieson, who points out that during a submergence, such as that which is indicated by the marine shell-beds of North-west Europe and North-east America, the areas occupied by ice-sheets were much circumscribed. The land-ice, instead of being at its maximum, was so far reduced as to be evidently inadequate to displace the earth's centre of gravity sufficiently to cause a rise of the sea to the required levels. Where, one might ask, was the great northern ice-cap at the time the Arctic regions were depressed to the extent of 2,000 ft.?

Another explanation of the fact that evidence of glaciation is so frequently accompanied by proofs of submergence has been advocated by Professor Penck and others, according to whom the submergence may have been brought about by the attraction exerted by the vast accumulations of ice.[2] The elaborate investigations of Woodward,[3] Drygalski,[4] and Hergesell,[5] however, have shown that although a certain amount of distortion of the hydrosphere would be caused by the presence of great ice-sheets, the utmost possible rise of the sea-level brought about in this way would be comparatively insignificant. The elevations at which marine

[1] *Climate and Time*, chaps. xxiii. xxiv.
[2] 'Schwankungen des Meeresspiegels,' *Jahrb. d. geogr. Ges. zu München*, Bd. vii. (1882).
[3] *Bull. U.S. Geol. Survey*, No. 48, vol. iii.; see also *U.S. Geol. Survey, Sixth Annual Report*, 1884-5, p. 291.
[4] 'Die Geoiddeformationen der Eiszeit,' *Zeitschr. d. Ges. für Erdkunde zu Berlin*, Bd. xxii. Heft 3, 4 (1887).
[5] *Beiträge zur Geophysik von Gerland*, 1887, Bd. i. pp. 69, 115.

deposits of glacial age occur are far in excess of any submergence which could have been induced by the attraction of an ice-sheet of the greatest conceivable dimensions.

The view set forth by Mr. Jamieson,[1] that the apparent rise of the sea-level in glacial times was induced by subsidence of the earth's crust under the weight of the ice-sheets, has been received with considerable favour by geologists. His leading idea is 'that the ice-covered regions were depressed by reason of the great weight of ice placed upon them, and that, when the ice disappeared, they rose again with extreme slowness, and may have eventually attained nearly their former level; but in most cases,' he believes, 'some amount of permanent depression probably occurred.' This hypothesis appears to explain so many facts, that geologists are naturally inclined to accept it. It accounts for the striking association of glaciation and submergence, and is from several points of view a plausible explanation enough. But we shall be able to test its feasibility only when we have all the data bearing upon submergence correctly correlated. At present this has not been done. So far as our knowledge of the facts goes, however, it accounts for these much more satisfactorily than the hypotheses supported by Croll and Penck. Nevertheless there were certain movements of depression in Pleistocene times which cannot be connected with glaciation. The occurrence of high-level rock-terraces at Gibraltar, and of raised-beaches on the coasts of the Levant, are evidence of considerable subsidence which cannot be attributed to sagging of the earth's crust under an ice-load. It may be objected, therefore, to Mr. Jamieson's hypothesis that the earth-movements to which the Arctic shell-beds of higher latitudes bear witness may similarly have been induced by other causes than the pressure of ice-sheets. It is not denied, however, that during the long-continued Pleistocene period the subterranean forces may have caused movements within the glaciated regions. But the almost constant association of submergence with glaciation, and the striking connection that appears to have obtained between genial climatic conditions and a wide land-surface, are certainly very suggestive. There is one well-known case

[1] *Geological Magazine*, 1882, p. 400.

of submergence, however, which seems to be an exception to the rule. I refer to the subsidence of a broad region in Scandinavia, under the waters of the Littorina Sea, the fauna of which is clearly indicative of more genial conditions than are now met with on the coasts of Sweden. The deposits of that sea occur at heights varying from 160 ft. to nearly 400 ft. above the present sea-level, and thus bear witness to movements which, as De Geer remarks, cannot be directly connected with an ice-load. I am not so sure that this case is really an exception. The *Littorina*-formation of Scandinavia, there is every reason to believe, is on the same geological horizon as the forty-five to fifty-feet raised beach of Scotland. Prior to the formation of that beach the British area appears to have been joined to the Continent, and its coasts to have extended far into the Atlantic—and this wide land-surface enjoyed a genial forest-climate. The subsidence that eventually succeeded was accompanied or immediately followed by a relapse to cold conditions, when local glaciers came down the Highland glens and in some places reached the sea. Yet the fauna of the beaches does not suggest anything like arctic waters—indeed, as we have seen, the shells in certain raised-beaches on the west coast indicate even warmer conditions than the present. Now if a recrudescence of glaciation supervened in Scotland, we may be sure that something similar, but on a larger scale, took place in Scandinavia also. The succession is so clear in Scotland that one might almost venture to predict the discovery erelong that the Scandinavian glaciers made an equally decided advance during the epoch of the Littorina Sea. But it is very difficult to believe that the depression of the earth's crust which brought about the final insulation of Britain, and submerged the Scottish coast-lands to the extent of fifty feet, could possibly have been induced by the weight of the local glaciers and their snow-fields. The snow-line at that time, as will be remembered, stood at an average elevation of 2,500 ft. or thereabout, and it is hardly conceivable that the pressure of the limited snow-fields and local glaciers possible under such conditions could have sufficed to produce any marked deformation of the crust. After this stage of depression had passed, the land

again emerged and attained a wider extent than it now has, and enjoyed once more genial forest-conditions. Are we to suppose that this re-elevation was due to the disappearance of snow and ice? And can we believe it possible that the subsequent re-appearance of glaciers fed from snow-fields lying above the level of 3,500 ft. caused the subsequent depression of the land which is indicated by the presence of the twenty-five to thirty-feet beach? Lastly, we may ask, was the weight of these insignificant snow-fields and glaciers so considerable that when they finally disappeared, the land, relieved of its load, rose to its present level?

Professor Chamberlin, who had been led independently to entertain the same views as Mr. Jamieson, suggested some years ago that 'another effect of the ice must have been to reduce the temperature of its rock-bottom to the freezing-point, and maintain it there so long as the ice remained, giving opportunity for the cooling and consequent contracting effects to be deeply and widely felt. While the co-efficient of contraction for rock is small, yet the total effect on a segment of the crust one hundred miles wide might be appreciable. Whatever influence this might have had would have been in the same direction as that produced by the weight of the ice, and would have been added to its effects.'[1] The same view has been set forth with his usual incisiveness by Dr. Drygalski, who points out that when an ice-sheet had dissolved, free radiation of earth-heat would be resumed, the depressed isogeotherms would rise and a general warming of the upper portion of the lithosphere would take place. But the space occupied by the depressed section, owing to the spheroidal form of the earth, would be smaller than that which it occupied before sinking had commenced, and, consequently, when the ice vanished, expansion of the crust would follow, and the land-surface would then rise again.[2] He is of opinion, therefore, that the earth-movements of glacial times were due principally to this

[1] *Geology of Wisconsin*, vol. iii. (1883) p. 290.

[2] 'Ueber Bewegungen der Kontinente zur Eiszeit.' *Verh. d. VIII. deutschen Geographentages zu Berlin*, 1889. Drygalski, during a recent visit to Greenland, ascertained that the ground underneath glacier-ice is frozen, while that outside of the glacier is not. (*Zeitschr. d. Ges. für Erdkunde zu Berlin*, Bd. xxvii. 1892.)

cause. According to Mr. O. Fisher, however, this view is untenable—any changes of level brought about in the way supposed by Drygalski must have been hardly appreciable.[1]

In fine, then, it may be said that geologists and physicists are still undecided as to what is the true explanation of the apparently causal connection between glaciation and depression—although the weight of opinion seems to be in favour of Mr. Jamieson's hypothesis. But, as I have shown, his explanation is not free from difficulties. If we admit as a possibility that the load of a great ice-sheet, several thousand feet thick, might produce more or less deformation of the lithosphere, we yet can hardly believe the crust to be so flexible as to yield to the pressure of the relatively insignificant weight of such snow-fields and glaciers as those of the fifth and sixth glacial epochs in Scotland. Were the crust so readily deformed, physicists should long ere this have discovered tidal movements in it, produced, like those of the sea, by the attractions of the sun and moon. The cause of the remarkable connection between glaciation and depression, therefore, is a problem which has not yet been satisfactorily solved. Mr. Jamieson's explanation is the nearest approach to a solution we have, for it shows not only that depression must have accompanied glaciation, but that the depression must have been greatest in the early glacial stages when glaciation was most extreme. So far the facts sustain the hypothesis. But, as I have pointed out, the final movements of depression and elevation which accompanied the appearance and disappearance of local glacial conditions, were on too large a scale to be due to the latter.

The question we have next to consider is even more perplexing, and has been and doubtless will continue to be a fruitful source of controversy. The cause of the Glacial Period itself has been sought for in the earth beneath and in the heavens above. Some, for example, have speculated upon the possibility of the whole solar system travelling onwards through the boundless realms of space, and passing in its course through warmer and colder tracts than that in which it now moves. When the sun with its attendant orbs swept through those hypothetical warm regions, the whole

[1] *Proc. Phil. Soc. Cambridge*, 1893.

climate of the world, it was supposed, would be affected, and tree-ferns and cycads might then flourish within the Arctic Circle, while the northern seas might be tenanted by large chambered shells and corals. But when, on the other hand, the colder abysses of space were traversed, a total change of climate would be experienced; the luxuriant vegetation would fade away from the Polar regions, and a bleak ice-cap would cover the poles of the globe and spread outwards as the cold increased, until the snow and ice might reach down to latitudes like our own.

Some writers, again, suppose that the Glacial Period may have been caused by a great increase in the obliquity of the ecliptic.[1] Others have speculated upon the possibility of our sun being a variable star of long period, shining at widely separated intervals with diminished radiance. Yet others have imagined a change in the position of the earth's axis of rotation, due to the elevation of extensive mountain-tracts somewhere between the poles and the equator. This, they think, would be sufficient to shift the axis, so as to confer upon regions which once were circumpolar the temperature of lower latitudes. But it has been demonstrated that the protuberance of the earth at the equator so vastly exceeds that of any possible elevation of mountain masses between the equator and the poles, that any slight change which may have resulted from such geological causes could have had only an infinitesimal effect upon the general climate of the globe. And even if it were possible that vast movements of the kind suggested could shift the axis of rotation, yet they would not account for the facts. For, as we have seen, there is a succession of glacial epochs to be accounted for. It is not, therefore, only one change in the position of the poles, but several that we should require; and all these stupendous changes, so improbable in themselves, must be supposed to have taken place at quite a

[1] Major-General Drayson, for example, believes that the pole of the heavens describes a circle round a point 6° distant from the pole of the ecliptic and 29° 25′ 47″ from the pole of the heavens. About 13,700 years B.C. the angular distance of the two poles, according to him, was 35° 25′ 47″, which would bring the Arctic Circle down to the centre of England. But even were such an increase of the obliquity of the ecliptic possible it would not account for the climatic conditions of the Glacial Period. For an examination of General Drayson's views see Croll's *Climate and Time*, 1875, p. 410.

recent date, and within a comparatively short space of time.[1]

Another attempt to solve the problem of great climatic changes was made many years ago by Mr. (now Sir John) Evans, who thought it possible that the crust or shell of the globe may have slid round the fluid or semi-fluid interior, and so brought the same areas of the external surface under very different conditions. It was thus conceived that lands, which at one time basked under a tropical sun, might in the slow course of ages be shifted to some more northern region, while countries which had for long years been sealed up in the ice of the Arctic Circle might eventually slide down to temperate regions.[2] Putting aside any question as to the physical possibility of this crustal wandering, the geological evidence alone justifies us in rejecting it as an explanation.

Sir Charles Lyell, as is well known, maintained that the climatic vicissitudes of the past could be accounted for by that continuous change in the distribution of land and sea which has been going on all through the ages. He thought that if the lands were massed chiefly in equatorial and tropical latitudes, the resulting climate of the globe would be such that extremely genial conditions would characterise polar regions. The land, heated to excess under the equatorial sun, would give rise to warm currents of air, which, sweeping north and south, would tend greatly to temper the climate of higher latitudes. On the other hand, were the land to be grouped chiefly round the poles, the reverse of all this, he believed, would come about; for with no land under the equator to soak up the heat of the sun, and give it to the winds to carry north and south to polar regions, the climates of the northern and southern hemispheres would be so greatly

[1] Professor G. H. Darwin thinks it is possible that as the continents have risen and fallen, the pole may have worked its way, in a devious course, some 10° or 15° from its geographical position at consolidation, or may have made an excursion of smaller amount and have returned to near its old position. 'This kind of wandering of the poles,' he says, 'would, of course, require extensive and numerous deformations, and it is hard to see how there can have been a shifting of the surface-weights sufficient to produce it without frequent changes in the geographical distribution of land and water. If, then, geologists are right in supposing that where the continents now stand they have always stood, would it not be almost necessary to give up any hypothesis which involved a very wide excursion of the poles?' (*Philosophical Transactions*, 1877, p. 271.)

[2] *Proc. Roy. Soc.*, No. 82, 1866.

affected, that snow and ice would then gather upon the ground, and creep gradually outwards down to those low latitudes where we now meet with their traces.[1]

We may well admit that the climates of the globe have always been more or less influenced, as they are in our own day, by the relative position of oceanic and terrestrial areas. But we are assured that no such distribution of land and water, as Lyell thought necessary for the production of our Glacial Period, ever obtained in Pleistocene times. We have no reason to doubt that the positions of land and sea were practically the same then as they are now. Nor, even if it could be admitted that the land-masses were, at so recent a period, massed chiefly in high northern and high southern latitudes, would that help us to explain the climatic conditions of the Glacial Period. We have a complex alternation of cold and warm epochs to account for, necessitating, on Lyell's hypothesis, successive re-arrangements of land and sea on so vast a scale as to be beyond belief.

Another view, which may be looked upon as a modification of Lyell's, is that which attributes the climatic changes of the Glacial Period to extensive movements of elevation and depression. We all know that overhead, at a less or greater height according to latitude, eternal winter reigns. In order to explain the glacial phenomena of temperate latitudes, therefore, some have supposed that those regions formerly stood at a greater elevation : only lift the lands high enough, and they will reach the snow-line ! I have elsewhere discussed this earth-movement hypothesis,[2] and endeavoured to show that no evidence is forthcoming to prove, or to render it probable, that the extensive elevations required have ever taken place, and that, even if we could suppose them to have occurred, they would yet fail to account for the phenomena involved. To explain the widespread evidences of glaciation by means of elevation it would seem necessary, I have said, 'to infer that all the affected areas were in Pleistocene times uplifted *en masse* into the Arctic Zone that stretches above our head. Now it seems easier

[1] *Principles of Geology*, vol. i. chap. xii.

[2] *Trans. Geol. Soc. Edin.* vol. vi. p. 209; *Journ. of Trans. Victoria Institute*, vol. xxvi. p. 221; *Fragments of Earth-Lore*, chap. ix.

to believe that the snow-line was lowered by several thousand feet than that the continents were elevated to the same extent. Glaciation, as we have seen, was developed in the same directions and over the same areas as we should expect it to be now, were the snow-line to be generally depressed. To put it in another way, were the snow-line by some means or other to be lowered over the northern hemisphere, then, with sufficient precipitation, great ice-fields and glaciers would reappear in the very regions which they covered during Pleistocene times. Neither elevation nor depression of the land would be required to bring about such a result. Certain advocates of the earth-movement hypothesis, however, do not maintain that all the glaciated areas were uplifted at one and the same time. The glaciation of the Alps, they think, may have taken place earlier or later than that of North-western Europe, while the ice-period of the Rocky Mountains may not have coincided with that of Eastern North America. It is not impossible, they suppose, that the glaciation of the Himalayas may have been caused by an uplifting of that great chain, quite independent of similar earth-movements in other places. It can be demonstrated, however, that the glaciation of the Alps and of Northern Europe were contemporaneous, and the facts go far to prove that the glaciers of the Rocky Mountains and the inland-ice of North-east America likewise co-existed. At all events the old glacial accumulations of our hemisphere are of [late Pliocene and] Pleistocene age, and it is for the advocates of the hypothesis under review to prove that they are not contemporaneous. Their doubts on the subject probably arise from the simple fact that they are well aware how highly improbable or even impossible it is that all those glaciated lands could have been pushed up within the snow-line at one and the same time.'[1]

And if we find it hard to conceive of movements of elevation affecting simultaneously nearly the whole land-surface of the northern hemisphere, our difficulties are not lessened by the reflection that we have still the glacial phenomena of the southern hemisphere to account for. The earth-movement hypothesis, in short, is quite inadequate as an explanation of

[1] *Fragments of Earth-Lore*, p. 278.

the former extensive development of glacial phenomena, and it equally fails to account for the climate of interglacial times. Its supporters have contended that when the highly elevated regions of their dreams were again depressed to what we may call a normal level, the snow-fields and ice-sheets would disappear and temperate climates would return. But I may point out that the geographical conditions which, according to their view, induced the retreat of glacial cold and the advent of genial interglacial times are precisely those that now obtain, and yet the strangely equable climate that permitted the development of the remarkable interglacial floras and faunas is not experienced in the Europe of our day. And what about the complex alternation of cold and warm epochs? Are we to suppose that all the lands have periodically been uplifted and depressed for thousands of feet again and again? And can it be believed that such vast oscillations of the crust could have taken place in so comparatively short a space of time? [1] It is true that many movements of depression and elevation occurred during the Glacial Period, but none of these was on the great scale required by this hypothesis. Further, we may admit that a causal connection probably obtained between those movements and glaciation. Elevation, however, did not bring about general glaciation, but the latter was perhaps the cause of depression, for with the disappearance of glacial conditions the sunken areas rose again.

Seeing that crustal movements alone fail to afford a solution of the glacial problem, is it not possible that this may be found in the relations of our planet to the sun? Geologists are justly jealous of attempts to account for the facts of their science by reference to causes other than those they see at work in the world around them. And perhaps the frequent failure of physicists and astronomers to frame a satisfactory theory for great changes of climate may some-

[1] The earth-movement hypothesis has been maintained, in one form or another, by Lyell, Dana, Le Conte, and many others. Recently it has been furbished up and extended by my friend Mr. W. Upham in an appendix to Dr. Wright's *Ice Age in North America*. See also the same author's papers in *American Geologist*, vol. vi. p. 327; *American Journal of Science*, III. vol. xli. p. 33; *Popular Science Monthly*, vol. xxxix. p. 665; *Journ. Victoria Institute*, vol. xxvi. p. 254.

times have been viewed by geologists with a kind of secret satisfaction.

It seems likely, however, that in this matter they must, after all, be content to follow the guidance of the astronomer and the physicist, seeing that their own science refuses, in this particular at least, to yield as much assistance as would be desirable. Nor, after he has sufficiently questioned all the natural causes with which his own peculiar studies have made him familiar, ought the geologist to feel surprised that these sometimes fail to explain the phenomena that come under his cognizance. There is no hard-and-fast line separating the domain of one science from that of another, and as the circle of knowledge widens boundary divisions become more and more difficult to determine. Perhaps of no science is this more true than that of geology. At one time the investigator into the past history of our globe had the field almost entirely to himself, and the limits of his study were as sharply defined as if they had been staked off and measured. Now, however, it would be hard to say on which of the territories of his scientific neighbours he must trespass most. He cannot proceed far in any direction without coming in contact with some worker from adjacent fields. His studies are constantly overlapping those of the sister sciences, just as these in turn overlap his. It will, therefore, only be a further proof of the unity of Nature if those intricate problems which have hitherto baffled the geologist should eventually be solved by the researches of astronomers and the conclusions of physicists. Stalwart supporters of Uniformitarianism may be induced to contemplate this possibility with equanimity when they remember that there is reason to believe that even in our own day the climate of the globe is subject to fluctuations which certainly cannot be explained by the urim and thummim of crustal movements. It has long been known that the glaciers of the Alps alternately advance and retreat. Now Professor Brückner has shown that there are likewise periodical changes in the level of the Caspian, the Black Sea, and the Baltic, and his observations have been extended and found to hold good also for the Neusiedler See and for many of the lakes in Armenia. These and similar phenomena connected with rivers sug-

gested to Brückner the probability that the fluctuations in question would be clearly expressed in the rainfall as recorded at meteorological stations all over the world. This he has found to be the case, and we now learn that every region of the earth experiences contemporaneously a more or less rainy period, and in the same way a dry period.

In the last two centuries the years 1700, 1740, 1780, 1815, 1850, and 1880 appear to mark the centres of wet periods, and the years 1720, 1760, 1795, 1830, and 1860 the centres of dry periods.[1] But rainfall is not the only meteorological element that exhibits a kind of rhythmical fluctuation. It is the same with temperature, for Brückner finds that the humid periods are likewise cool periods, while the dry ones are warm. No doubt secular fluctuations of rainfall are due to fluctuations in atmospheric pressure, but these last can only be the result of periodical changes of temperature. Here, then, we have apparently minor oscillations of climate which can hardly be attributed to other than cosmical causes. Whatever their cause may be, Brückner is perhaps right when he remarks that he who discovers the origin of temperature fluctuations will at the same time discover the cause of climatic changes.[2] If it be true, then, that minor oscillations of climate, which cannot be attributed to earth-movements, are taking place in our own day, it is not improbable that similar changes on a much larger scale may have been effected in past times quite independently of any modification in the distribution of land and water.

The several hypotheses referred to in preceding pages as having been advanced to explain the origin of the climatic changes of the Glacial Period have each been objected to by physicists. But from my point of view they stand condemned, chiefly because they all alike fail to meet the requirements

[1] These epochs are not absolutely the same; thus the epoch of minimum rainfall during the present century ranged from 1856-60 in some regions, and in others from 1861-5; and analogous variations characterised the maximum rainfall; but in no case did a minimum in one place ever coincide with a maximum elsewhere. It may be added that the fluctuations are more marked towards the interior of continents than in maritime districts.

[2] 'Die Schwankungen des Wasserstandes,' &c. (*Ann. der Hydrogr. und Maritimen Meteorolog.*, 1888, Heft iv.; 'In wie weit ist das heutige Klima konstant?' *Verh. d. VIII. deutsch. Geographentages in Berlin*, 1889; *Klimaschwankungen seit* 1700, &c., Vienna, 1890; *Verhandl. der* 73. *Jahresversammlung der schweizerisch. Naturforsch. Ges. in Davos*, 1890.

of the geological evidence. There remains now only another theory to be considered—that, namely, which is associated with the name of the late Dr. James Croll.[1] Like its predecessors, it has met with considerable opposition from some physicists, while by others it has been no less strenuously supported. Into this discussion I do not propose to enter. The theory, I believe, will stand or fall according as it explains or fails to explain the geological evidence. If its conclusions accord with the results obtained by geologists we shall be justified in adopting it until some more complete explanation shall be advanced to take its place. If, on the other hand, it fails to account for the cardinal facts—for the salient features of glacial history—it must be rejected, no matter what may be said in its favour by astronomers and physicists. According to the theory in question, the climatic changes of the Glacial Period resulted from the combined influence of precession of the equinoxes and secular changes in the eccentricity of the earth's orbit. At present winter in the northern hemisphere occurs when the earth is nearest the sun, while our summer, of course, takes place when the earth is farthest away from that luminary. But it will not always be so. Our summer solstice will not always, as now, nearly coincide with aphelion, but will slowly draw up to perihelion, until in 10,500 years we shall have a disposition of the seasons corresponding to that which presently obtains in the southern hemisphere: afterwards a continuation of the motion will in other 10,500 years bring round again our present arrangement. This is what is called the precession of the equinox. The orbit or path of the earth round the sun (the *ecliptic*) is somewhat elliptical, and, owing to the attractions of the other planets, its *shape* slowly changes. Thus at one time it approaches nearly to a circle, and at another time it becomes more flattened or elliptical. These deviations are confined within certain limits, between which they are constantly oscillating backwards and forwards. The eccentricity during a long lapse of years goes on decreasing till it sinks to a minimum value, and the orbit then

[1] *Climate and Time* and *Climate and Cosmology*. In the latter work the author supplements his theory and replies to his critics. See also for an interesting discussion of the question, Dr. Wallace's *Island Life*.

approaches most nearly to a circle, without, however, ever becoming actually circular. After passing this point the eccentricity begins to increase, and the orbit becomes more and more flattened, till the maximum eccentricity is reached. Then the cycle of changes comes slowly round again in reversed order; the orbit gradually draws nearer and nearer to a circle till a minimum is arrived at, when it again begins to grow elliptical, and continues to alter in this direction till the next maximum is reached. At present, the path is slowly approaching the more circular route, and in about 24,000 years from this date the ellipticity will reach one of the minimum points. After that the earth will again begin to follow a more and more elliptical course round the sun, until, when thousands of years have elapsed, its orbit shall have attained its maximum eccentricity; and then the ellipticity will again slowly diminish as before. It is important to notice that the intervals between consecutive turning-points are very unequal in length, and the actual maximum and minimum values of the eccentricity are themselves variable. In this way it comes about that some periods of high eccentricity have lasted much longer than others, and that the orbit has been more elliptical at some epochs of high eccentricity than at others.

When the maximum of ellipticity is attained, the earth in aphelion will, of course, be farther from the sun than it is now at that point in the ecliptic; while, on the other hand, the earth in perihelion will be nearer. At present the mean distance of the earth from the sun is some 92,400,000 miles, but when the eccentricity of the orbit is at its superior limit —in other words, when the planets by the force of their attraction have succeeded in pulling the earth as far from the sun as they can—the earth in aphelion will then be 99,584,100 miles from the sun, while in perihelion it will be only 85,215,000 miles. The earth will therefore be 14,368,200 miles farther from the sun in the former than in the latter position. Of course the reader will understand that while the earth's orbit varies in its degree of ellipticity, the time taken by the earth to complete a revolution round the sun never does. All that the planets do is to modify the shape of the path traversed by the earth. At the pre-

sent time the ellipticity of the orbit is such that the earth, when nearest to the sun or in the perihelion part of its course, receives in a given time one-fifteenth more heat than it does in aphelion. Now, this being the case, it is quite evident that, did the earth travel round the sun at the same rate in all parts of its orbit, or, in other words, were the seasons of equal duration, the southern hemisphere, which has its summer in perihelion, would not only, as it does now, receive more heat *per diem* than the northern, but its annual proportion would also be greatly in excess. But this is prevented by the unequal pace at which our globe hurries on its way—the result being that both sections of the world receive the same yearly amount of heat. Dr. Croll pointed out that the present difference between the two hemispheres, as regards the proportion of heat derived from the sun in a given time, would be vastly increased when the eccentricity reached its highest value. If at a period of maximum eccentricity the winter of our hemisphere should happen in aphelion, we should then be receiving one-fifth less heat during that season than we do now, and in summer-time, of course, one-fifth more. But if, on the other hand, our winter should, as at present, fall in perihelion, the effect of a great ellipticity would be such as to annihilate the difference between summer and winter in the latitude of this country. In other words, while one hemisphere enjoyed a kind of perpetual summer the other would be enduring the greatest extremes of summer heat and winter cold.

During a period of great eccentricity of the earth's orbit, the earth in aphelion would be about nine millions of miles farther from the sun than it is now, and the present long frigid winter of the southern hemisphere would then become still longer, and the cold more intense. If it happened to be the northern hemisphere whose winter occurred in aphelion, of course similar climatic results would ensue, and the mean temperature of our winter would fall below the freezing-point. Consequently, all the moisture precipitated in our latitude during that season would fall in the form of snow, and the British seas would be frozen over. Nor would the greater proximity of our hemisphere to the sun in perihelion avail to free these islands from their frost. It is true that

the direct heat received in perihelion during the summer of a period of great eccentricity would exceed that which we now derive during that season by one-fifth ; but this intense heat, paradoxical as it may seem, would not give rise to a warm summer. The summers of North Greenland, we know, are colder than our winters, notwithstanding that the rays of the sun in that region are so strong as to melt the pitch on the sides of ships. Everyone, indeed, has heard of the heat of the arctic sun, which shines day and night during the whole summer-tide. But despite the sun's power the mean temperature of summer in North Greenland does not exceed one or two degrees above freezing-point, and this is entirely owing to the presence of snow and ice. Were it not for these, the sun would heat the ground, and the ground would impart its warmth to the atmosphere, and the summer temperature would then rise to something like our own. It is only in this way, or from passing over warm water, that the air can be heated, for the direct rays of the sun pass through it without sensibly affecting it. Now in the polar regions the sun's heat is used up chiefly in melting snow and ice, and not in warming the ground ; so that comparatively little of the summer heat finds its way into the atmosphere by radiation. Such being the case, it is not difficult to follow Dr. Croll when he argues that the sun, during a period of great eccentricity, would not be able to give a warm temperature to that hemisphere whose summer happened in perihelion. An increased amount of evaporation would certainly take place, but the moisture-laden air would be chilled by coming in contact with the vast sheets of snow that had gathered during the long intolerable winter, and hence the vapour would condense into thick fogs, and cloud the sky. In this way the sun's rays would to a large extent be cut off, and unable to reach the earth, and consequently the winter snows would not be all melted away. Nor, supposing there were drenching rains during the summer, would these suffice to dissolve more than one-eighth part of snow and ice—for, as Dr. Croll remarks, 'it takes nearly eight tons of water at 58° Fahr. to melt one ton of snow.'

The accounts given by voyagers who have sailed in the south polar seas are often highly interesting, as showing the

great difference in climate between lands situated at the same distance from the poles in the two hemispheres. They all agree as to the intenser cold of the Antarctic as compared with the Arctic summer, and to the greater frequency of cold raw fogs in the southern polar regions. Captain Forster, of the 'Chanticleer,' who spent several months making observations at Deception Island, mentions specially the thick fogs and strong gales which he encountered. The fogs indeed were so frequent and thick that for ten days neither sun nor stars were seen, and the air was so intensely raw and cold that Lieutenant Kendal did not remember to have suffered more at any time in the Arctic regions. And yet this was in January, the very midsummer of the south, and in a latitude corresponding to that occupied by the Færöe Islands, where the climate is much the same as in our own Shetland. Now, when we remember that this cold raw summer of the south happens while the earth is actually nearer to the sun than it is at the time the milder northern polar regions have their summer, we cannot but admit that mere proximity to the sun will not necessarily produce a warm season.

At the time of greatest eccentricity, when the earth would be nearer to the sun in perihelion than it is now, there can be no doubt that the heat received would be correspondingly increased. But during the long winter of aphelion—longer by thirty-six days than the summer of perihelion—such an accumulation of snow and ice would have taken place, that even the diminished distance between the earth and sun in summer-time would be powerless to effect its removal; and so it would go on increasing year by year, until all northern countries (winter happening in aphelion) down to the latitudes of these islands were swathed in a dreary covering of snow and ice. There would then be a glacial period over our hemisphere, while at the antipodes a very different condition of things would obtain. Supposing, as before, that the precession of the equinoxes had caused the summer of the southern hemisphere to happen at the time the earth was in aphelion, we should then have a climate for our antipodes exactly the opposite to that which, as Dr. Croll has shown, a maximum eccentricity would confer upon the northern hemisphere. The heat received would be less in a given time,

but then summer would be thirty-six days longer, while winter would be much milder, and correspondingly short, owing to the sun being nearer than in summer by more than eight millions of miles. The result of all this would be to equalise the seasons. There would be a long cool summer and a short genial winter, during which probably little, if any, snow would gather; and thus there would be an approach to what Herschel has called a 'a perpetual spring.'

There is another set of circumstances, however, which would help powerfully to increase the difference between the two hemispheres. The trade-winds exist, as everyone knows, by reason of the unequal temperature of the atmosphere at the equator and the poles. The air is heated under the equator and rises to flow towards the poles, while cold currents set from the poles towards the equator to restore the equilibrium. At present all the constant oceanic currents appear to flow out of the Antarctic Ocean. In this way the wide Equatorial Current is only a continuation of the great Antarctic Drift-current, which, flowing north-east, enters the Indian Ocean, sending one branch by the west coast of Australia northwards through the Indian Archipelago, and another stream westwards, so as to strike the east coast of Africa. Leaving the Mozambique Channel, this great current now doubles the Cape, and then continues on its course north-westwards along the African coast, until eventually, sweeping across the whole breadth of the Atlantic, it divides, one stream flowing south along the coast of Brazil, and the other striking for the Gulf of Mexico, from which, when it issues, it takes the name of the Gulf-stream.

During such a glacial condition of things as would follow upon a great increase in the eccentricity of the earth's orbit the air in the northern hemisphere (supposing the winter of that hemisphere to occur in aphelion) would be chilled down to a much lower temperature than in the corresponding latitudes of the opposite hemisphere. And as such would necessarily be the case, it follows that the aërial currents flowing from the poles to restore the equilibrium which the upward set of the heated air under the equator had disturbed would be of unequal strength. The winds from the severe wintry North would sweep with much more vigour towards

the equator than the opposite winds from the South Pole. And hence Dr. Croll contends that with weaker winds blowing from the south the great Antarctic Drift-currents would be reduced in volume, while the subsidiary currents to which they give rise, namely, the broad Equatorial and the Gulf-stream, would likewise lose in volume and force. And to such an extent would this be the case, that, supposing the outline of the continents to remain unchanged, not only would the Brazilian branch of the Equatorial Current grow at the expense of the Gulf-stream, but the Gulf-stream, he thinks, would eventually be stopped, and the whole vast body of warm water that now flows north be entirely deflected into the southern oceans. For the same reason also the currents of the Pacific, which carry so much warmth from the tropics to the north, would also be turned back. If such were the case, we can easily conceive that the reduction of temperature caused by the withdrawal from the north of all these great ocean-rivers of heated water would be something enormous. But so much loss to the northern hemisphere would be just so much gain to the southern, which would have its temperature raised to such a degree that, in place of a 'perpetual spring' there might well be 'perpetual summer' within the Antarctic Circle.

There is yet another consideration which Dr. Croll has emphasised. 'A strong undercurrent of air *from* the north implies an equally strong upper current *to* the north. Now if the effect of the undercurrent would be to impel the warm water at the equator to the south, the effect of the upper current would be to carry the aqueous vapour formed at the equator to the north; the upper current, on reaching the snow and ice of the temperate region, would deposit its moisture in the form of snow; so that it is probable that, notwithstanding the great cold of the glacial epoch, the quantity of snow falling in the northern regions would be enormous. This would be particularly the case during summer, when the earth would be in perihelion and the heat at the equator great. The equator would be the furnace where evaporation would take place, and the snow and ice of temperate regions would act as a condenser.' We can see also that immediately south of the ice-covered regions,

as in the Mediterranean lands, the increased precipitation would give rise to marked pluvial conditions.

Lastly, we may note that during a period of great eccentricity of the earth's orbit the range of temperature would be extreme, and, as Mr. McGee has pointed out,[1] the effect of that increased range would be to diminish the mean temperature. Again, Rev. E. Hill has shown [2] 'that as temperature increases evaporation increases, but many times as fast—in fact with a transcendental ratio.' Hence the increased range of temperature induced by great eccentricity would increase the mean evaporation, and therefore the mean precipitation.

Sir Robert Ball has recently pointed out that Dr. Croll has understated his case, and that the Astronomical theory of the Glacial Period is really a most complete explanation of great climatic mutations. He remarks that although it is quite true that the heat received on the whole earth from vernal to autumnal equinox equals that received on the whole earth from autumnal to vernal equinox, it is not true, as Croll and others have supposed, that the heat received on either hemisphere during summer is equal to that received during winter. In point of fact, almost twice as much heat reaches a hemisphere in summer as in winter. 'Of the total amount of heat received from the sun on a hemisphere of the earth in the course of a year, 63 per cent. is received during the summer, and 37 per cent. is received during the winter.' Such being the case, it is obvious that when eccentricity attained a high value the differences between the seasons would become greatly accentuated. There must have been epochs when our hemisphere had a summer of 199 days and a winter of 166 days, and there were also epochs when, owing to the precession of the equinox, the conditions were exactly reversed—the winter enduring for 199 days and the summer for only 166 days. In each case, however, the figures 63 and 37 represent the proportional quantities which the northern hemisphere received in summer and winter respectively. Thus 63 measures of heat would come in summer and 37 in winter, no matter what the length

[1] *Amer. Journ. of Science and Arts*, vol. xxii. (1881) p. 437.
[2] *Geol. Mag.* vol. viii. (1881) p. 481.

of those seasons might be. Sir Robert remarks: 'There is another mode of expressing the same result which possesses some advantages. If the daily average receipt of heat from the sun on a hemisphere be taken as unity, then, of course, the receipt during the whole year will be represented by 365; this is not, however, imparted uniformly, for 229 of these units are contributed during summer and 136 during winter. This exhibits in a rather instructive manner the extreme contrasts between the climates of the two hemispheres that have occasionally arisen. We express them as follows:—

INTERGLACIAL.

229 heat measures spread over 199 days.
136 „ „ „ 166 „

GLACIAL.

229 heat measures spread over 166 days.
136 „ „ „ 199 „

How far then, we may ask, does the theory set forth by Dr. Croll and supplemented by Sir Robert Ball explain the facts ascertained by geologists? Let us consider first the glacial phase. We have seen that during cold conditions there appears to have been a general lowering of the snow-line—a regular displacement of climatic zones. Not only was the snow-line depressed, but precipitation was much greater than it is now. The mean temperature of our hemisphere was lowered, while at the same time the ratio of precipitation was increased, snow falling in abundance in temperate and northern regions, while in more southern latitudes copious rain took the place of snow. Again, the dominant set of the currents in the Atlantic was from north to south. Here, then, the theory exactly accords with the geological evidence.[1] As regards the interglacial phase, the agreement between the theory and the facts is not less striking. During the climax of an interglacial epoch the

[1] During the maximum epoch of glaciation in our hemisphere it is most probable that the Arctic Ocean was permanently frozen to a considerable depth, and thus played the part of a land-surface. Under such conditions, as my friend Dr. Buchan has pointed out to me, all the ice-covered regions of the North would form an area of high pressure. On the other hand, more southerly latitudes would form areas of great evaporation, and therefore of low pressure. Thus the dominant winds in the North Atlantic would come from high latitudes, as Croll inferred, and the surface-drift of the oceanic currents consequently would be southward.

summer was not so hot and dry as now, while the winter was much more genial—an oceanic climate prevailing far into the east of Europe. At the same time the prevalent direction of the Atlantic currents was from south to north. The theory also maintains that there must have been an alternation of such cold and warm epochs, and that the coldest and warmest epochs occurred at a time when the eccentricity was at its highest value. Now, according to Croll, that happened in the earlier stages of the last great cycle of eccentricity which extended over 160,000 years. The geological record ought therefore to show that the earlier glacial epoch or epochs were colder than those that followed. Now it has been proved that the maximum glaciation supervened in early Pleistocene times, and that three or four separate and distinct cold epochs of diminishing severity succeeded. Of these last the first seems to have been almost as severe as that which preceded it, and it certainly much surpassed in severity the cold epochs of the later stages. But the epoch of maximum glaciation was not the earliest glacial epoch. It was preceded by one of less severity than itself, but which, nevertheless, seems to have been almost as important as that which came after the epoch of maximum glaciation. Hence it would appear that the correspondence of the geological evidence with the requirements of the Astronomical theory is as close as we could expect it to be. Without relying too much on the well-known 'imperfection of the geological record,' it is obvious enough that the earliest glacial epoch of which we have any evidence may have been preceded by less strongly-marked oscillations of climate. It is probable, in short, that what I have called the first glacial epoch was really not the earliest cold stage of the last great cycle of maximum eccentricity. It may well have been preceded by a minor glacial epoch, just as the second and most extreme glacial epoch was followed in time by several cold stages of successively decreasing severity. It is, therefore, not unreasonable to infer that the epoch of greatest cold may have been heralded by a series of cold stages of increasing severity; but as the eccentricity reached its highest value not long after the commencement of the cycle, it is obvious that the minor cold epochs that preceded the

epoch of maximum glaciation would be fewer in number than those that followed after it. Again, if it be true that the coldest glacial epoch happened in the earlier stages of the great cycle, it would follow likewise that the warmest interglacial epochs should have occurred immediately before and after that epoch, the succeeding genial epochs approximating more and more nearly to the conditions that now obtain in temperate regions. Now, so far as one can judge from the character of the interglacial floras and faunas, this is precisely what happened. The Elephas-meridionalis stage immediately preceded, and the Elephas-antiquus stage immediately succeeded the epoch of maximum glaciation, while the faunas and floras of subsequent interglacial stages approximated more closely to those of the present day.

According to the Astronomical theory, a glacial epoch in the northern hemisphere was necessarily contemporaneous with interglacial conditions in the southern hemisphere, and *vice versa*. It is of course impossible to prove from geological evidence that this was actually the case. The records of the Pliocene and Pleistocene periods in the two hemispheres are too widely separated 'by mount, and stream, and sea,' to allow of any close correlation. All we can say is that there is nothing in the evidence to forbid the probability that the glacial deposits of the one hemisphere are contemporaneous with the interglacial accumulations of the other. If it be said that we have no certain knowledge of the occurrence of interglacial deposits in the southern hemisphere, it may be replied that the geology of the regions involved has not been studied in the same detail as the corresponding tracts in Europe and North America. When the glacial phenomena of the Australasian highlands, South Africa, and South America, have been subjected to as close and careful scrutiny as the glacial accumulations of northern latitudes, we shall know a good deal more about them than we do at present. The evidences of glacial action, especially in mountain-regions, are always more conspicuous than the traces of interglacial conditions, and it is the former, therefore, that first attract attention. The glacial phenomena of the northern hemisphere had been long known and more or less well understood before the occurrence of interglacial deposits

was recognised. And even after the existence of the latter had been ascertained, some time elapsed before their meaning could be appreciated.

So far, then, as we have gone the Astronomical theory would appear to offer the best solution of the glacial puzzle. It accounts for all the leading facts, for the occurrence of alternating cold and warm epochs, and for the peculiar character of glacial and interglacial climates. It postulates no other distribution of land and sea than now obtains; it calls for no great earth-movements all the world over. It has been objected, however, that if this theory be true, glacial epochs must frequently have happened in earlier geological times. We ought, it is said, to find more or less clear indications of glacial conditions in all the great geological rock-systems. Whatever view we take as to the age of the earth, we must admit that the formation of Palæozoic, Mesozoic, and Cainozoic systems occupied enormous intervals of time, during which the eccentricity of the earth's orbit must have attained again and again a high value. It must be observed, however, that for the production of vast ice-sheets like those of the Pleistocene period, a wide land-surface is required. You cannot have broad tracts of 'inland-ice' if you have no continental areas upon which the snow and ice can accumulate. If in earlier geological times no continuous land-masses, comparable to those of our own day, extended from temperate into high northern regions, periods of great eccentricity might have come and gone without inducing excessive glaciation anywhere. Even were it true, therefore, that the older geological systems exhibited no traces of former extensive glaciation, this would not necessarily be any argument against the probability of the Astronomical theory. We should require first to know whether the geographical conditions during earlier stages of the world's history were such as would induce widespread glaciation under the influence of extreme eccentricity of the earth's orbit. Now, as I have elsewhere shown,[1] we have good grounds for believing that throughout Palæozoic times the primeval continental ridges were to a great extent under water—that, in short, the dry lands of the globe consisted of groups of larger and smaller

[1] *Fragments of Earth-Lore*, p. 353.

islands scattered over what are now our continental areas. A remarkable uniformity of climate accompanied these insular conditions. In Mesozoic times the primeval continental plateau came more and more to the surface, but the land-areas were still much interrupted, so that free oceanic communication obtained between southern and northern latitudes. The climate therefore remained insular and uniform, but was apparently not so markedly so as in the preceding era. In Cainozoic times the land-masses continued to extend, and this persistent land-growth was accompanied by a gradual lowering of the temperature of northern and temperate latitudes, and a more and more marked differentiation of climate into zones. In the earlier stages of the world's history, therefore, the geographical conditions could not, as a rule, favour the accumulation of vast ice-fields. The effects of high eccentricity of the orbit would to a large extent be neutralised. During such a cycle there might be fluctuations of temperature in high latitudes. There might well have been, for example, a general lowering of temperature, sufficient to render the climate of northern seas and lands somewhat cooler, and probably to induce the appearance in suitable places of local glaciers; and, owing to the precession of the equinox, these cooler conditions would be followed by a general elevation of the temperature above the normal for the geographical conditions of the time. But nothing like the glacial and interglacial phases of the Pleistocene period could have occurred. Here and there local glaciers might have descended to the sea-level, not only in northern, but in temperate latitudes, and icebergs might now and then have drifted about and dropped erratics upon the bed of the sea. One might have expected, therefore, occasionally to meet with such evidences of former ice-action, and a reference to the Appendix (Note A) will show that erratics of the kind have been not infrequently encountered in the sedimentary rocks of various geological systems. When it is remembered that these systems consist for the most part of marine accumulations, it becomes evident that the records of warm and temperate conditions are more likely to be preserved than traces of cold and glacial climates. The former will usually be represented

by abundantly fossiliferous beds, while in the case of the latter the only relics that are likely to be preserved are ice-floated erratics. The ice-markings on the rocks, and the morainic accumulations of mountain-valley and lowland, are almost certain sooner or later to be obliterated. Take, for example, the glacial deposits of Pleistocene times. Even now the action of the weather, of frost, and rain, and rivers, is slowly but surely effacing the marks left by the old glaciers. So long a period has elapsed since the lowlands of Britain were overflowed by ice, that ice-markings have mostly vanished from exposed surfaces. Should our islands eventually become submerged, it might well be that, as the land sank down, what the atmospheric forces had failed to obliterate would succumb to the action of the sea. Should the land be afterwards re-elevated, it is doubtful whether more than a few shreds of boulder-clay would remain to testify to the former existence of wide-spread glacial conditions. The farther back we go in time, therefore, the more difficult must it become to detect evidence of ice-action. The older systems consist for the most part of deposits which gathered on the floors of ancient oceans. Very few land-surfaces have been preserved. Consequently, if we are to find in the older systems any traces of former glacial cold, it will consist for the most part of scattered stones and boulders embedded in marine accumulations. Nevertheless, there are not wanting, even in Palæozoic systems, deposits which bear a strong resemblance to morainic débris. Of course, when we are dealing with formations so far removed from us in time—formations in which the organic remains depart so widely from existing forms of life, we can hardly expect to derive much aid from the fossils in our attempts to detect traces of cold climatic conditions. The arctic shells in our post-tertiary clays are convincing proofs of the former existence in our latitude of a severe climate; but when we go so far back as Palæozoic ages, we have no such clear evidence to guide us. All that palæontologists can say regarding the fossils belonging to these old times is simply this, that they seem to indicate, generally speaking, mild, temperate, or warm conditions of climate. Many of these fossils, indeed, if we are to reason from analogy at all, could not possibly have

lived in cold seas. But, for aught that we know, there may have been alternations of climate during the deposition of each particular system; and these changes may be marked by the presence or absence, or by the greater or less abundant development of certain organisms at various horizons in the strata. Notwithstanding all that has been done, our knowledge of the natural history of these ancient seas is still very imperfect; and therefore, in the present state of our information, we are not entitled to argue, from the general aspect of the fossils in our older formations, that the temperature of the ancient seas was never other than mild and genial.

There are so many ways in which stones and boulders may have been transported, that the occurrence of erratics buried in marine strata cannot always be cited as proof positive of the action of floating ice. We must not lay too much stress upon all the cases of block-transport referred to in the Appendix. Fortunately, however, the evidence of glacial action in earlier ages is not limited to these, for striated boulders and glaciated rock-surfaces of very great antiquity have been preserved. Thus Dr. Hans Reusch has cited the occurrence in the Varangerfiord of a massive conglomerate, in which he detected distinctly ice-smoothed and striated stones and boulders, the whole mass presenting the character of a moraine. More than this, the conglomerate rested upon a clearly-smoothed and striated rock-surface. There is some doubt as to the age of this morainic deposit, but Reusch thinks it probably belongs to Cambro-silurian times. Dr. Dahll, on the other hand, assigns it to the Permian period. It is, at all events, of Palæozoic age. Striated subangular and blunted rock-fragments also occur in some of the Old Red Sandstone conglomerates of Scotland —the deposits exposed in the Lammermuir Hills having all the appearance of morainic accumulations and sheets of frost-riven rock-rubble. More remarkable still are the evidences of glacial action which have been furnished by the Permian and Permo-carboniferous rocks, both of the northern and the southern hemisphere. The Permian breccias of Britain, the remarkable boulder-beds of Talchír and the Salt Range of India, the Dwyka conglomerates of South Africa, and the similar accumulations of Victoria,

New South Wales, and Tasmania, are now generally believed to belong to the same geological horizon. It is also generally admitted that they owe their origin in some way or other to glacial action—in short, they are evidence that cold climatic conditions obtained in Permian or Permo-carboniferous times, in widely separated regions. In keeping with this conclusion is the long-recognised fact that the Permian period was one of transition, during which the Palæozoic plant-life of the globe suffered eclipse—most of the characteristic types of Carboniferous times becoming exterminated. It is probable, therefore, as E. Forbes, Dana, H. F. Blanford, Wallace, and others have suggested, that this remarkable impoverishment of the Palæozoic floras was brought about by those wide-spread cold climatic conditions of which the breccias and conglomerates with their striated erratics are the direct records.

Referring the reader to the Appendix for further details as to this and the evidences of glacial action at other periods of the past, I submit that the testimony of the rocks apparently favours the Astronomical theory of the origin of glacial climates. Up to the dawn of the Pleistocene period the geographical conditions of the world appear as a rule to have been more or less insular, and could not therefore favour the production of great ice-sheets comparable to those of the Glacial Period. Now and again, however, the distribution of land and sea, as in Permian times, would seem to have been better adapted for that purpose. In short, the general character of the geological evidence is just what might have been expected. Sporadic wandered blocks are present to suggest the former existence of icebergs and local glaciers—while at wider intervals appear heaps and sheets of breccias, conglomerates, and boulder-beds, resting occasionally on grooved and polished rock-surfaces. Further, such proofs of glacial conditions are accompanied by evidence of the whole-sale extinction of life-forms—more especially of land-plants.

Another objection to the Astronomical theory, as set forth by Dr. Croll, has been urged by some geologists. According to Croll, the last great cycle of eccentricity to which he assigned the Glacial Period began some 240,000 years ago, lasting for 160,000 years, and thus terminating about 80,000

years ago. In this cycle he included the more strongly-contrasted glacial and interglacial epochs. The more recent and less pronounced oscillations of climate—those, namely, which are represented by the later valley-moraines, raised-beaches, and buried forests of Scotland—might well belong, he considered, to the present stage of moderate eccentricity. According to this view, therefore, the last considerable glaciers—those which deposited their moraines upon our 50-ft. beach—need not date further back than 10,000 or 12,000 years. I have already remarked on the difficulty of drawing a line between glacial and postglacial times. So far as I can read the evidence the cycle of climatic oscillations which commenced in the Pliocene period did not terminate abruptly. On the contrary, the oscillations appear to have become successively less and less pronounced until they merged into the present. But if a line of separation must needs be drawn for purposes of classification and arrangement, then the Glacial Period proper might be held to have closed with the disappearance of the last Great Baltic Glacier and the District Ice-flows of Britain. This, the latest epoch of extreme glaciation, would have terminated, according to Croll's theory, about 80,000 years ago. Objections have been urged against this date—some writers being of opinion that no such long period has elapsed since the deposition of the great terminal moraines of North America and the corresponding accumulations in Europe. These objections have been suggested by various estimates of the time required for the erosion of valleys and the accumulation of alluvial deposits since the conditions in question passed away. Mr. Gilbert, for example, concludes that the postglacial gorge of Niagara, at the present rate of erosion, must have been cut out by the river within 7,000 years, while Mr. Winchell obtains for the postglacial erosion of the Falls of St. Anthony (Minnesota) a period of 8,000 years. The observations and researches of Professor Spencer, however, show that the question of the age of the gorge of Niagara is a very complex one, and that Mr. Gilbert's estimate is probably much under the truth. He writes me that his results may be summarised as follows:—

	Years.
1st epoch of Falls, draining only the Erie basin, with a discharge of $\frac{3}{11}$ths of all the waters of the upper lakes, cascading 200 ft. from lake to lake	17,200
2nd epoch, in former part of which the discharge was $\frac{3}{11}$ths and afterwards all the upper lake waters, with total fall of 420 ft. This was an epoch of a series of three falls, the lower receding faster than the highest	11,200
3rd epoch.—Falls united and cascading over 420 ft.	800
4th epoch, modern.—Falls cascading 320 ft. from crest of rapids above falls to lake below	3,000
Total . .	32,200

The question of the age of the erosion is, as I have said, a very complex one and need not be further considered here. Under certain contingencies the falls may have commenced, Mr. Spencer remarks, some 17,000 years before the end of the Ice Age, while it is quite possible that under certain other contingencies the Glacial Period proper may have terminated some 80,000 years ago. Other estimates by American authors, based on rates of erosion and sedimentation, might be cited to show that since the close of the Ice Age only some 7,000 or 10,000 years have elapsed. If these could be relied upon we should be compelled to the conclusion that the Glacial Period proper in North America did not coincide with the same stage in our own Continent, for no European geologist will hazard the suggestion that the last great Baltic glacier existed at the dawn of civilisation in Egypt. With every respect for the ingenious labours of those who have attempted to ascertain the duration of postglacial times by means of such measurements and estimates, I submit that their conclusions are, in the nature of things, unreliable. At most all they have succeeded in showing is that the close of the Glacial Period proper was, geologically speaking, not very remote—which is just what we have believed for many years. But into what number of centuries we ought to translate the words 'not very remote,' we cannot tell. Yet when geologists are agreed as to where the line should be drawn between the glacial and the postglacial deposits of Europe and North America as a whole, it may be possible to arrive at some approximately satisfactory estimate of the time which has elapsed since the close of the Glacial Period. Until this has been done, however, our estimates cannot possibly harmonise, and are necessarily worthless. It may

well be that the great Terminal Moraines of North America and those of the last Baltic Glacier were accumulated at a less remote period than Croll supposed. But even if this could be proved, it would not necessarily overturn the Astronomical theory. It is quite possible that Croll's estimate of the date of the last great cycle of eccentricity may be excessive. Such estimates, according to Sir Robert Ball, depend upon formulæ which cannot be relied upon when very distant periods are concerned. The numerical elements of these formulæ are dependent on planetary observations extending over 2,000 years at most. For the past 2,000 years, therefore, and perhaps for the next 2,000 years to come, they may be trusted, but to apply them to a state 80,000 years ago would appear to be an unreliable extrapolation. Thus the truth of the Astronomical theory nowise depends on the accuracy of Croll's determination of the date of the Glacial Period, which may have commenced and ended later than he supposed.

But although that theory seems to account for the major oscillations of climate—although its interpretation of the complex changes of the Glacial Period is so clear, coherent, and consistent that one can hardly doubt it contains a large element of truth—still there are certain phenomena which it seems hardly to explain. I refer to the minor climatic oscillations of so-called 'postglacial' times. It seems to me that the Buried Forests, Valley- and Corrie-moraines, and Raised Beaches of North-west Europe are evidence of a succession of changes, too manifold and perhaps occupying too short a space of time to be accounted for by the particular causes to which Croll appealed. Those later climatic changes, as I have tried to show, were apparently only the final manifestation of the more strongly pronounced cold and genial phases which preceded them. It may be that the earlier climatic oscillations were due to one cause, and the later changes to another. But that is not probable, and as a geologist I cannot separate them. In our glacial and so-called 'postglacial' deposits we apparently have the records of one long cycle of time, characterised above all by strange climatic fluctuations, which, after they had reached their culmination early in the period, declined successively in

importance until finally they faded away into the present. The primary cause of those remarkable changes is thus an extremely perplexing question, and it must be confessed that a complete solution of the problem has not yet been found. Croll's theory has undoubtedly thrown a flood of light upon our difficulties, and it may be that some modification of his views will eventually clear up the mystery. But for the present we must be content to work and wait.

APPENDIX.

NOTE A.

Table of Geological Systems.

Post-tertiary or Quaternary	Postglacial and Recent stage. Series of Glacial and Inter-glacial stages = Pleistocene.*
Tertiary or Cainozic . .	Pliocene.* Miocene.* Oligocene. Eocene.*
Secondary or Mesozoic .	Cretaceous.* Jurassic.* Triassic.*
Primary or Palæozoic .	Permian.* Carboniferous.* Devonian and Old-Red-Sand-stone.* Silurian.* Cambrian.* Precambrian.*

The systems marked with an asterisk have all yielded supposed evidence of ice-action. In several cases, however, the facts may be otherwise interpreted.

The Precambrian sandstones and conglomerates of Scotland occasionally assume the aspect of morainic accumulations, but no glaciated stones have been observed.

Dr. Hans Reusch has described the occurrence in the Varangerfiord, not far from the Norwegian and Russian border-line, of unstratified conglomerate which rests upon a glaciated surface. The rock is a reddish, clay-bearing sandstone, crowded with erratics of gneiss, granite, diorite, dolomite, and quartz. Some of the finer grained stones are distinctly glaciated, and none of the fragments has the appearance of having been water-worn. The conglomerate, he says, looks quite like boulder-clay. Its age is undetermined—Dr. Dahll assigning it to the Permian, while

Dr. Reusch considers it to be of Cambrian or Silurian age.[1] Here also we may note the occurrence of large boulders, embedded in a fine matrix, in the old 'transition series' of India. The geological horizon of this boulder-bed is not known, but it is apparently older than the Silurian, and may be of Cambrian or Precambrian age. The bed rests upon a striated rock-surface.[2]

In the Himalayas of Pángi, south-east of Kashmir, boulders occur in great numbers in certain slates which are supposed to be of Silurian age.[3] Similar boulders (from one to five feet in diameter) are found embedded in Lower Silurian greywackés in the south of Scotland (Glen App and Dalmellington).[4] They consist of granite, gneiss, diorite, various schists, &c., all of which are foreign to the district, and have probably been derived from some region composed of Precambrian rocks. No ice-markings have been observed upon any of the boulders. Boulder-beds of a like character have been found in Ireland. Sir W. Dawson has recorded a somewhat similar occurrence in the Lower Silurian of Maimanse, Lake Superior, where a conglomerate contains boulders two feet in diameter. Again, in the Upper Silurian of Nova Scotia, the same author has detected angular stones and chips, 'the materials of which seem precisely similar to that which is at present produced by the disintegrating action of frost on hard, and especially schistose and jointed rocks.'[5] Mr. James Stirling has recorded the occurrence of striated boulders in the Upper Silurian conglomerates of the Gibbo River, Australia.[6]

The Old Red Sandstone conglomerates in the north of England and in Scotland have appeared to several competent observers closely to resemble consolidated boulder-drift.[7] Among other instances, mention may be made of the conglomerates of Kirkby Lonsdale and Sedburgh. The Scottish conglomerates often present the appearance of morainic débris, being frequently unstratified, while the stones show that peculiar subangular blunted aspect which is characteristic of glacial work. In these deposits my brother, Sir A. Geikie, has detected many striated stones. Here and there traces of water-action are conspicuous, the stones assuming a somewhat water-worn appearance, and being arranged in more or less regular beds. In the unstratified masses, however, the rock-fragments are confusedly huddled together in a tough arenaceous matrix, and the accumulation then closely resembles a boulder-clay. It is typically developed in the Lammermuir Hills, but similar deposits are met with in Ayrshire and other regions in the west of Scotland.

Erratics have been detected in certain Carboniferous strata in France, which, according to Mr. Godwin-Austen, may have been transported by floating ice.[8] Pebbles and boulders not infrequently occur embedded in

[1] 'Skuringsmærker og Morængrus,' &c., *Norges geol. Undersögelses Aarbog*, 1891.
[2] *Records Geol. Surv. India*, vol. x. p. 13.
[3] *Manual of the Geology of India*, first edit. p. xxxvi.
[4] *Explanation of Sheet Ayrshire* (Geol. Surv. of Scotland), p. 8.
[5] *Canadian Naturalist*, vol. ii. p. 6; vi. p. 416.
[6] *Proc. Austr. Assoc. Adv. Science*, 1889, vol. i. p. 359.
[7] *The Reader*, August 12, 1865; Cumming's *History of the Isle of Man*, p. 86: Horne, *Trans. Edin. Geol. Soc.* vol. ii. p. 325.
[8] *Quart. Journ. Geol. Soc.* vol. xii. p. 58.

coal-seams. Many examples are cited by Mr. Gresley from the Coal-measures of England. He mentions the discovery in a coal-seam of a group of five boulders of quartzite, which varied in size, the smallest weighing 6¾ oz., the largest 11 lbs. 8 oz. All these were probably carried down entangled in the roots of trees.[1] Rounded stones have also been found embedded in coal-seams in various places in Silesia and Moravia,[2] but none of these can be cited as cases of ice-transport. Similar evidence is forthcoming from the Carboniferous strata of North America. Thus, in Ohio, a quartzite boulder, measuring 17 ins. by 12 ins., was found embedded in a seam of coal and overlying shale. Professor Newberry thought it possible that this boulder might have been carried by ice down some ancient Carboniferous river.[3]

Sir A. C. Ramsay has described the occurrence, in English Permian breccias of numerous erratics, varying in size from a few inches to two, three, or even four feet in diameter, which had come, he thought, thirty to forty-five miles from their parent rocks. Many of these stones are angular and subangular and blunted, presenting the characteristic appearance of the stones in a boulder-clay. Sometimes they show polished and striated surfaces. Ramsay, therefore, inferred that the breccias pointed to the existence in Permian times of glaciers and floating ice, and he further suggested that similar accumulations occurring on the same geological horizon in Germany told the same tale of former cold conditions.[4] Professor Hull has observed like traces of ice-action in Permian breccias in Ireland.[5] Ramsay's conclusions have been extended to account for similar phenomena in the Permian or Permo-carboniferous system of South Africa, India, Australia, and Tasmania. The South African boulder-beds were recognised in Natal many years ago by Dr. Sutherland as of glacial origin. He pointed out that they were quite analogous to the boulder-clays of Northern Europe. They contain erratics, some of which measure 6 ft. across and weigh from 5 to 10 tons. Many of the stones have been transported for 60 or 80 miles from the nearest rock *in situ*. This deposit rests upon a smoothed and grooved surface of Carboniferous sandstone.[6] It is known generally as the 'Dwyka-conglomerate,' and occurs at the base of the Karoo formation, which from its organic remains would seem to range in age from the Carboniferous to the Trias. In Cape Colony, as in Natal, this conglomerate has yielded large erratics and striated boulders, and likewise rests upon a glaciated rock-surface. In short, it is an unstratified mass, and most geologists who have seen it are convinced of its glacial origin.[7] Professor Green, however, thought it might be a coarse shingle formed along a receding coast-line.[8] But Dr. Schenck's careful examination, not only of the conglomerate but of the smoothed rock-

[1] *Geol. Mag.*, 1885, p. 553.
[2] C. E. Weiss, *Jahrb. d. k. k. geol. Reichsanstalt*, Bd. xxxv. p. 242; D. Stur, *ibid.* p. 613.
[3] *Rep. Geol. Surv. of Ohio*, 1870.
[4] *Quart. Journ. Geol. Soc.* vol. vi. p. 197; *Phil. Mag.* vol. xxix. p. 290.
[5] *Expl. of Sheet* 47 (Geol. Surv. of Ireland).
[6] *Quart. Journ. Geol. Soc.* vol. xxvi. p. 514.
[7] See Griesbach, *Quart. Journ. Geol. Soc.* vol. xxvii. p. 53; Stow, *ibid.* p. 514; Dunn, *Report presented to both Houses of Parliament*, Cape Town, 1886, p. 7; A. Schenck, 'Ueber Glacialerscheinungen in Süd-Africa,' *Habilitationsschrift, Friedrichs-Universität Halle-Wittenberg*, 1889.
[8] *Quart. Journ. Geol. Soc.* vol. xliv. p. 243.

surfaces on which it rests, leaves little room for doubt that we have here to do with true glacial phenomena. He gives the direction of glaciation as NNE. to SSW., which is parallel to the borders of the Cape Plateau. In Bengal and the Central Provinces of India occur the famous boulder-beds of Talchír, first distinguished by Messrs. W. T. and H. F. Blanford in 1856. Some of the boulders measure more than six feet across, and they very often occur in a fine-grained silt-like rock. The stones 'are almost always rounded, probably by torrents, and as the beds are entirely destitute of marine remains, there is every probability that the transporting agent was river-ice.'[1] Near Chánda the bed yielded some polished and striated boulders, and the underlying surface was similarly smoothed and striated.[2] This remarkable boulder-bed occurs at the base of the Gondwána system. In the Salt Range of the Punjaub, Mr. Wynne discovered another boulder-bed, likewise yielding polished and scratched erratics, which has since been correlated with the Talchír bed. It is most remarkable that this boulder-bed should be so widely distributed over India—occurring not only in Bengal and the Central Provinces, but in the Nerbudda Valley, the desert of Rajputána, and in the Punjaub.[3] Dr. Blanford is of opinion that the bed is of the same age as the Dwyka-conglomerate of South Africa and the similar boulder-beds of Australia, and the same view is held by Mr. R. D. Oldham. Sir R. Daintree was apparently the first to suspect the glacial charàcter of the latter.[4] Grooved and striated stones were observed in the conglomerates on the Lerderberg River, and special reference is made to the mixture in the conglomerates of coarse and fine, angular and water-worn materials, much of which had clearly been derived from a distance. A few years later Mr. R. L. Jack, Government geologist of Queensland, also recognised the evidence of glacial action in the conglomerate-beds of the Bower-River Coal-field. He describes the occurrence of large isolated erratics of granite in the midst of fine sandy and argillaceous strata, 'which could hardly have been brought to their present positions except by glacial action.'[5] Mr. R. D. Oldham, of the Geological Survey of India, visited Australia for the purpose of comparing the Talchír beds with the conglomerates of Australia, and was able to confirm the views first suggested by Daintree as to the marine glacial transport of the latter. He found abundant evidence of the action of floating ice.[6] Since then similar evidence has been

[1] *Quart. Journ. Geol. Soc.* vol. xlii. p. 251.

[2] T. Oldham, *Mem. Geol. Surv. India*, 1872, p. 324; Fedden, *Records Geol. Surv. India*, 1875, p. 16.

[3] For references see Blanford's paper already cited, and *Manual of the Geology of India*. Dr. Feistmantel has ably discussed the evidence of a Permo-carboniferous glacial period from the palæontological point of view, and correlates the Talchír and Salt-Range boulder-beds with the Dwyka conglomerate of South Africa, and the similar boulder-beds of New South Wales and Victoria (*Sitzungsber. der k. böhm. Ges. d. Wissensch. Prag*, 1887, p. 1). See also Dr. Waagen on the Carboniferous glacial period, *Jahrb. d. k. k. geol. Reichsanstalt*, Bd. xxxvii. p. 148. The same author describes the occurrence of large and small erratics in the Carboniferous rocks of South Brazil (*Neues Jahrb. für Min., Geol. u. Pal.* 1888, Bd. ii. p. 172), which, alike in their general aspect and in the paucity of organic remains, closely resemble those of Australia, India, and South Africa.

[4] Daintree, *Report on the Geology of Ballan, Victoria*, 1866, p. 11; see also Selwyn's *Physical Geology and Geography of Victoria*, p. 16.

[5] *Report on the Bower-River Coal-field*. Brisbane, 1879.

[6] *Records Geol. Surv. India*, 1886, Pt. 1.

adduced by Mr. T. W. E. David from the Carboniferous strata of New South Wales.[1] Of recent years the conglomerates of Bacchus Marsh (between Melbourne and Ballarat) have been closely studied by a number of observers, each of whom supports the view of their glacial character. Mr. E. J. Dunn, for example, recognises the erratic origin of much of the material, consisting as it does of various granites, gneiss, schists, quartz-rock, &c., which range in size from fine grit up to blocks several feet across, and weighing in some cases probably from twenty to thirty tons. Some of the stones are well rounded, others are roughly angular and unabraded, while many are scored and scratched, and great numbers are rubbed on one or more sides.[2] The same geologist describes the character and constituents of the conglomerate exposed in Wild Duck Creek as follows :—'Perhaps the first thing that attracts attention in this conglomerate is the indiscriminate manner in which huge boulders, great angular and sub-angular masses, pebbles, and fragments of rock of endless variety of size, form, and material, are commingled, sand and clayey matter binding the whole into a solid mass. Many of the boulders, pebbles, &c., are of unusual form, or bear peculiar markings or modifications of their original form. Angular and subangular stones have been rubbed into shapes that water-action would not produce; boulders and pebbles, evidently rounded by water, have flat sides ground on them, or bear marks not attributable to water-action. From the mass examples are obtainable in abundance that have been planed, scored, striated, scratched, and polished, besides which many cases occur in which the edges of the stones are broken away, evidently through others pressing heavily against them. Planing is very common; it is sometimes flat, or, in other cases, the surface is hollowed, or there may be a convex surface; in either case the marks of grinding action are traceable in the hollow or on the convex portion as well as across the flat surfaces. In the case of the erratic known as "the Stranger" the present top surface must at one time have been wider, and it is planed for its whole length and breadth, both the felspar and quartz being cut down level.' This erratic is a mass of coarse-grained granite measuring 16 ft. 6 ins. in length by 10 ft. 6 ins. in breadth, at the widest part, and about 5 ft. in thickness. Its perimeter is 44 ft., its average breadth 8 ft., and it probably weighs about thirty tons. Mr. Dunn remarks that 'scratches are abundant on most of the stones. On the intensely hard rocks, such as quartzites, &c., fine scratches are noticeable with a glass; on soft pebbles very delicate scratches are observable, especially when freshly detached from the conglomerate; they are present in the hollows as well as the prominences of the stones.' Beds of sandstone are intercalated with the conglomerate, streaks of sandstone occurring in the conglomerate, and thin strips of conglomerate being embedded in the sandstone. The bedding of the sandstone is very irregular. The stones show an almost infinite variety of granites, syenites, gneisses, schists, quartzites, sandstones, slates, shales, conglomerates, amygdaloids, porphyries, vein-quartz, jaspers, &c. Many of these rocks are foreign to Victoria, and although fragments similar to the bed-rock of the country are present, 'it does not

[1] *Quart. Journ. Geol. Soc.* vol. xliii. p. 190.
[2] *Proc. Austral. Assoc. for Adv. of Science*, 1890, p. 452; *Proc. Roy. Soc. Vict.* vol. xxiv. Part 1.

follow that even they are of local origin.' At one place the bed-rock is well-exposed for a length of 60 ft., and shows a planed and striated surface—the parallel striæ running nearly north and south—the direction of movement having apparently been from south to north. Mr. Dunn is of opinion that the striation of the boulders has been effected by glacier-ice, but that the deposit has been dropped from floating ice. It is obvious, as he remarks, that blocks weighing many tons could not have been transported by running water, 'nor would water-borne material present the heterogeneous mixture of huge blocks and rounded masses, smaller boulders, pebbles, and angular fragments, sand and clay, all unsorted and indiscriminately commingled, with the longer axes as frequently vertical as horizontal. Icebergs that started their career as glaciers alone would account for the phenomena presented by this conglomerate.'[1] Mr. Graham Officer, my friend and former pupil, and Mr. Lewis Balfour have also given some account of the glacial conglomerate of Bacchus Marsh. In proof of its glacial character they point to the unstratified nature of the clayey matrix, the number and variety of the included stones, the striated and glaciated aspect of many of these, and their total want of arrangement. Mr. Officer, who is acquainted with the glacial phenomena of Scotland, Ireland, and Switzerland, was struck with the close resemblance of the conglomerate to *till* or boulder-clay, and he and his colleague could hardly doubt that it had a similar origin. Upon removing some portion of the conglomerate so as to expose the underlying bed-rock, they found the surface of the latter fluted and striated—the grooves and striæ indicating ice-movement from the south. And shortly afterwards Mr. Brittlebank showed them a *roche moutonnée* which he had uncovered, and which, on being still further cleared of the superincumbent conglomerate, 'presented the appearance of three smooth parallel ridges, well scored and striated, with well-rounded grooves six or more inches deep between. Here, as before, the striæ and grooves run north and south. Both Mr. Dunn's report and Messrs. Officer's and Balfour's paper have photographic illustrations of striated boulders and glaciated rock-surfaces which leave no doubt whatever as to the character of these. Mr. Officer has kindly sent me a considerable collection of stones from the conglomerate, each of which I recognise as having been smoothed and striated by glacial action. Had I not known their source I should have supposed that they had been taken from an ordinary boulder-clay or ground-moraine. Messrs. Officer and Balfour are of opinion that the Bacchus Marsh region has been invaded by glacier-ice, coming from the south, and that the conglomerate is a ground-moraine. Since the publication of their paper they have extended their researches, and Mr. Officer writes me (September 1893) that in Coimadai Creek, about seven miles from Bacchus Marsh, they found excellent sections, showing much of the conglomerate stratified, and lines of boulders occurring in it as if dropped on a level surface. He mentions the occurrence of two fine boulders of granite, both well scored. One of these is ten feet long, the other measured over eight feet. More than half of the latter had been broken up—the block being originally seventeen feet in length. These boulders occur in

[1] 'Notes on the Glacial Conglomerate,' Wild Duck Creek; *Department of Mines: Special Reports.* Victoria, 1892.

bedded clay, and had evidently been dropped by icebergs. In this locality the underlying Silurian bed-rock is exposed again and again, and shows the usual grooved and striated surfaces—the direction of ice-movement being from SSW. to NNE., thus agreeing with an earlier observation made by Mr. Brittlebank. Mr. Officer thinks that 'after the ice-sheet had passed over the country, and had retreated for some distance, either submergence ensued or large glacial lakes were formed in which floating ice drifted.' He has recently (May 1894) sent me some photographs of the glaciated rocks of Coimadai. These are characteristic *roches moutonnées*, showing the usual smoothed and scored surfaces. Mr. Brittlebank, who has been working at these remarkable conglomerates for a number of years, has written, in association with Mr. Sweet, some account of the deposits.[1] In a letter received from him last year (April 1893), he says that the evidence is quite sufficient to demonstrate that Victoria has been invaded by an ice-sheet coming from SSW. In the Werribee Gorge (six miles west of Bacchus Marsh), in Pyke's Creek (ten miles west of the Gorge), and in the Lerderberg Ranges (about eight miles north of the Gorge), the surface of the Silurian is well glaciated. 'At one place, where the surface of the bed-rock inclines at an angle of 25° towards the south, it shows projecting bosses, all of which are finely grooved and striated. The *Stoss-seite* exposed towards the south is rounded off and highly polished where the rock is hard, and deeply scored in others. These projecting bosses have evidently partially deflected the ice, as is shown by the way in which the striæ curve round them. In other places large wedge-shaped slabs of the bed-rock have been removed—the base of the wedges facing the south.' From the sketches sent me one can readily distinguish between the smooth glaciated *Stoss-seite* and the rough unabraded *Lee-seite*. The glacial series in the region described by Mr. Brittlebank evidently shows much more stratified material than in the districts visited by Messrs. Officer and Balfour. He says the series consists of a set of conglomerates, finely bedded shales, and sandstones, in some of which plant-remains occur, such as three species of *Gangamopteris*. The whole thickness of the series exceeds some 5,000 ft., as exposed in Korkuperrimal Creek. Striated and water-worn stones are thickly scattered through the sandstones and mudstones or shales. The conglomerates at this place are composed chiefly of water-worn stones, with here and there a few striated ones, which seem to have been exposed to the action of water. In some of the conglomerates occur large blocks of granite, porphyry, and a fine-grained greenish sandstone. All these are beautifully grooved and striated, and are not in the least degree water-worn. Everywhere the beds repose on a grooved and striated rock-surface. So far as I can gather from my friendly correspondents, there would seem to be a basement conglomerate, quite unstratified in places, and above that a great succession of sandstones, shaly mudstones, and intercalated boulder-beds. Mr. Officer writes me, after having visited the region described by Mr. Brittlebank, that it would almost seem as if glacial conditions had been repeated again and again, but perhaps these later displays were not so severe as they had been during the formation of the Bacchus Marsh conglomerates described by him and Mr. Balfour. Be that as it may, it is evident that in Victoria

[1] *Austr. Assoc. for Adv. of Science*, Sept. 1893.

we have the records of what must have been a most pronounced glacial period. The few plant-remains met with are not sufficient to determine with certainty the precise geological horizon of the beds, but they are certainly intermediate in age between the Carboniferous and the Trias, and there seems no reason to doubt their correlation with the Talchír boulder-beds of India, and the Dwyka-conglomerate of South Africa. They are probably, in short, of Permo-carboniferous age. To go into further details would extend this note beyond due bounds, and I need only mention further that similar boulder-beds have been detected in New South Wales, where they seem to occupy the same horizon.[1] Frequent reference is also made to the occurrence of large erratics in the Permo-carboniferous series of Queensland.[2] In Tasmania, likewise, similar evidence is forthcoming, huge erratics and polished and striated blocks of rocks, foreign to the country, occurring in the Permo-carboniferous system at Maria Island, One Tree Point, and throughout the south-eastern part of the island. Everywhere these boulder-beds and erratics are found in more or less unfossiliferous zones of the 'lower marine' beds of the system.[3] For the most part the erratics occur sporadically embedded in fine homogeneous mudstone, which shows scarce a trace of lamination. The larger erratics (granite and quartzite) generally appear singly, and look as if they had been quietly dropped from floating ice upon a soft muddy sea-floor. The evidence now adduced, and which is necessarily compressed and very imperfectly set forth, suggests a difficult problem. That the parallel striæ and flutings, and the *roches moutonnées*, which underlie the conglomerates

[1] R. D. Oldham, *Records Geol. Surv. India*, 1886, Pt. i. p. 39; *Manual of Geol. of India*, 2nd edition.

[2] *The Geology and Palæontology of Queensland and New Guinea*, by R. L. Jack and R. Etheridge, pp. 77, 151. The correlation of the Permo-carboniferous boulder-beds of India, Australia, and Africa is admirably discussed by Mr. Oldham (*Manual Geol. India*, 2nd edit. chap. viii.). This geologist draws attention to the fact that in New South Wales evidences of ice-action occur on two horizons. The boulder-beds of Bacchus Marsh, &c., are on the same horizon as the lower marine beds of the New South Wales Carboniferous system. These beds are charged with fossils occurring in such a condition as to show that the animals lived and died where their exuviæ are now found. Scattered through the fine-grained deposits containing the remains in question are numerous more or less sub-angular erratics of all sizes, up to several feet in diameter, some of them being glacially striated. The flora of the over-lying Coal-measures is of the same type as the corresponding beds in India (lower Gondwánas). Above the succeeding 'Upper Coal-measures' comes a group of sandstones and shales (Hawkesbury Series), in which occur large angular fragments of shale embedded confusedly at all angles in a matrix of sand. It is difficult, Mr. Oldham remarks, to account for the phenomena without the agency of ice in one form or another, and he thinks the evidence indicates the action of winter ice rather than of actual glaciers. (See for descriptions of supposed glacial action in Hawkesbury Series, C. S. Wilkison, *Trans. Roy. Soc. N. S. W.* vol. xiii. p. 106; T. W. E. David, *Quart. Journ. Geol. Soc.* xliii. p. 193.) No evidence of this recurrence of glacial conditions has been recorded from the corresponding series in India, but Mr. Oldham thinks it probable that the presence of undecomposed felspar in the sandstones of the Pánchet group (the upper member of the Lower Gondwána) indicates cold conditions. Sandstones containing undecomposed felspar would be likely to be formed under cold conditions. 'They mean that the disintegration of the parent rock from which the material was derived, together with the transport and final accumulation of the débris, went on at a greater rate than chemical decomposition of the constituent minerals, and this might be due either to extreme dryness, which would retard the rate of decomposition, or to an extreme severity of climate, which would accelerate the rate of disintegration.

[3] R. M. Johnstone, *Proc. Roy. Soc. of Tasmania*, 1884, p. 20; *ibid.*, 1886, p. 23; 1893 (June).

of Victoria, are the work of glacier-grinding can hardly be disputed. At all events that is the belief of those who are most familiar with the evidence. Mr. Brittlebank thinks that these glaciated rock-surfaces are due either to an invasion by the South Polar ice-cap or to huge glaciers descending from high lands to the south, which have since disappeared. That the ice came from the south or south-west all are agreed. The stratified beds with their erratics, the same observer believes, were deposited during subsequent submergence, when the ice-sheet was retiring. So long a time has elapsed since the Permo-carboniferous period that almost any amount of change may have taken place in the distribution of land and water between Australia and the Antarctic. The present great depths that separate those two regions may well be of comparatively recent origin. Many reasons, indeed, might be given for suspecting that the Antarctic lands at no very distant geological period extended much farther north towards South Africa and Australia. Mr. Brittlebank's speculation is therefore far from being so extreme as might be supposed. The occurrence of glacial accumulations in Central India is a much harder nut to crack, and would seem to indicate a more extensive and severe glaciation than that of the glacial period of Pleistocene times.

The Triassic rocks of Devonshire have yielded erratics which Mr. Godwin-Austen thought had been transported by floating ice. According to Mr. Pengelly, however, they need not have travelled far, but have been moved along an old coast-line by breaker-action.

In the north of Scotland a coarse boulder-conglomerate is associated with the Jurassic rocks of Sutherland, the possibly glacial origin of which was long ago suspected by the late Sir A. C. Ramsay.[1] Professor Judd subsequently suggested that the erratics had been floated down by ice from the Highland mountains, and dropped upon the bed of the Jurassic sea.[2]

The Cretaceous system has likewise yielded erratics which Godwin-Austen thought had been carried by ice.[3] Such erratics have been met with also in the Cretaceous rocks of the Alps. Some of these, however, may have been transported seawards entangled in the roots of trees, and others again may have been floated away from some old coast-line by large sea-weeds. But according to Godwin-Austen, with whom Sir C. Lyell agreed, only coast-ice could have transported the blocks, &c., found in the White Chalk near Croydon. Messrs. W. J. Sollas and A. J. Jukes-Brown have given a list of similar erratics which occur in the Upper Greensand of Cambridge.[4]

The great belt of sandstones known as 'Flysch,' which extends along the northern flank of the Alpine Lands from the south-west of Switzerland to the plains of the Danube at Vienna, is supposed to range in age from the Cretaceous to the Oligocene—a large proportion probably belonging to the Eocene system. Fossils very rarely occur in these sandstones, and the few that are met with do not enable the precise horizon of the deposits to be determined. Interbedded with the sandstones occur conglomerates

[1] *Phil. Mag.* vol. xxix. p. 290.
[2] *Quart. Journ. Geol. Soc.* vol. xxix. p. 195.
[3] *Ibid.* vol. xiv. p. 262; xvi. p. 327; *Geologist*, 180, p. 368; *Brit. Assoc. Rep.*, 1857, p. 62.
[4] *Quart. Journ. Geol. Soc.* vol. xxix. p. 11.

and breccias, which have all the appearance of shore-accumulations. But besides these, isolated blocks and groups of blocks occur irregularly scattered through the finer-grained beds. Some of these attain a large size; blocks 10 ft. long being not uncommon, and one even measured 105 ft. in length, 60 ft. in breadth, and 45 ft. in height.[1] A portion of the stones (of sedimentary character) may have come from different parts of the Alps, while the source of others (crystalline) is unknown. Recently, M. Ch. Sarasin has shown that a number of the erratics of crystalline rock are identical in character with rocks which occur in the Southern Alps, while some closely resemble those of the Finsteraarhorn. M. Sarasin points out that the sporadic blocks are obviously closely related in point of origin to the breccias and conglomerates. Most of the granites, porphyries, and gneisses which occur in the Flysch of Switzerland have come, he says, from the Southern Alps—so that at the time of the formation of the Flysch a free communication obtained between the north and south—in other words, the Central Chain of the Alps had not at that time been upheaved. Even as late as early Miocene times, according to Früh, similar conditions obtained. In pre-Miocene times he thinks the watershed of the Alps lay much farther to the south. Sarasin is of opinion that while the conglomerates probably owe their origin to torrents which swept the rounded stones down to sea, the sporadic blocks and coarse breccias have more probably been carried by ice.[2] Studer suggested that the conglomerates and breccias might be the coast-formations of some sunken mountain-mass, but for the former existence of this sunken mountain no direct evidence is forthcoming.

The Miocene of the Moncalieri-Valenza hills, in Northern Italy, contains great blocks of Alpine rocks, which, according to Gastaldi, must have been transported by floating ice.[3] This explanation has been extended to account for similar phenomena in the Tertiary rocks of other parts of Europe.[4]

The Pliocene and Pleistocene systems embrace, of course, the glacial and associated deposits which form the subject of this volume.

The preceding notes make no pretension to be complete. But the curious student will find in the references given further references to the literature of the subject. He should also consult Lyell's *Principles of Geology*, vol. i. chaps. x. and xi.; Dr. Croll's *Climate and Time*, chap. xviii., and A. Geikie's *Text-book of Geology*.

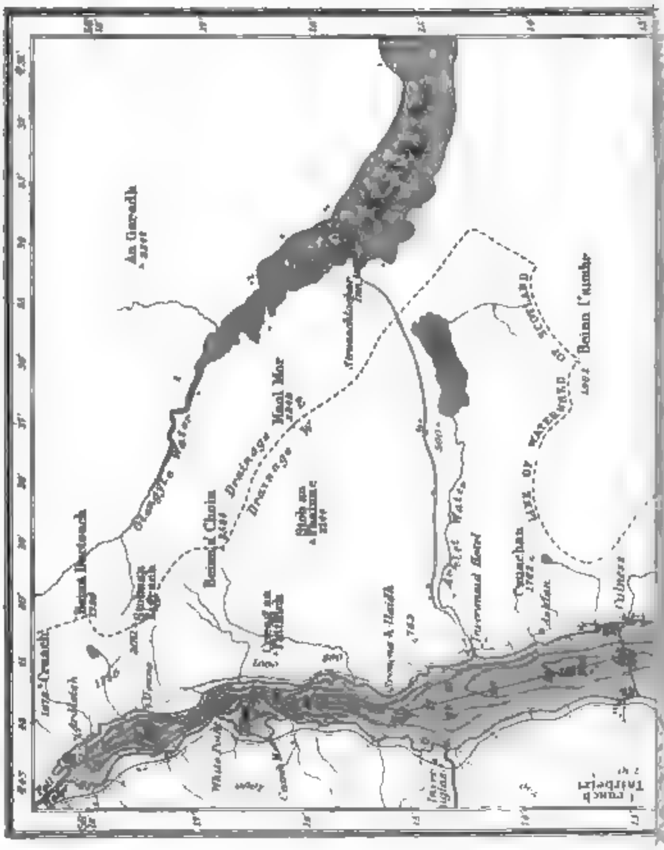
[1] Bachmann, *Vierteljahrsschr. d. naturforsch. Ges. in Zürich*, Bd. viii. (1863), p. 1.

[2] *Neues Jahrb. für Min., Geol. u. Pal.* viii. Beilage-Bd. p. 180.

[3] *Memorie della R. Accad. delle Scienze di Torino*, Ser. ii. t. xx. (1861).

[4] See Jules Martins, *Observations sur divers Produits d'origine glaciaire en Bourgogne*, 1878. The phenomena described by Martins have been otherwise accounted for by Delafond (*Bull. Soc. géol. de France*, 3e Sér. t. iv. p. 665); Arcelin (*Ann. de l'Acad. de Mâcon*, 1877), and Falsan (*Note sur l'origine de l'argile à Silex des environs de Mâcon et de Chalon*, 1878). For further notices of Tertiary erratic or boulder-accumulations, see *Bull. Soc. géol. de France*, 2e Sér. t. xxv. p. 695; t. xxvii. p. 559; t. xxix. pp. 541, 547; 3e Sér. t. iv. p. 184; *Congrès intern. d'Anthrop. et d'Archéol. préh.*, 1871, p. 86; *Jahrb. d. k. k. geol. Reichsanst.* Bd. xxix. p. 112; *Boll. Com. Geol. Italia*, 1878, p. 443.

PLATE XVI



SECTION OF LO

SECTION ACROSS LOCH L

NOTE B.

Map and Sections of Loch Lomond. (Plate XVI.)

This map and the accompanying sections are the work of my friend, Mr. R. L. Jack. The sections are drawn on a true scale (same as the map), and are designed to give a clear idea of what is meant by a true rock-basin. It will be observed that the lake is deepest in its narrow upper reaches, where, half-way between Inveruglas and Tarbet, it attains a depth of 100 to 105 fathoms. In its lower and wider reaches it shallows to 20, 12, 5, and 1 fathom. But so gradual is this shallowing, that were the lake to be drained of all its water, we should hardly be able to discover, without levelling, which was the deepest part of the hollow. The horizontal section brings out this feature in a striking manner. When, therefore, mention is made of a rock-basin 100 fathoms deep, we are not to think of a profound hole like a huge pit, but of an elongated cavity, overlooked it may be on both sides by more or less steep mountains or hills, and sloping in from both ends at a degree of inclination so slight as to be imperceptible to the eye. Were the Lake of Geneva to be drained, its bed would have merely the appearance of a gently undulating plain (yet that lake reaches a depth of 1,090 ft.), and the cavity occupied by Loch Lomond would not be more conspicuous.

Loch Lomond is a very interesting and satisfactory example of a rock-basin. We are quite sure of its depth, because it has been sounded all over by the officers of our navy, and we know that it does not lie in a line of dislocation or gaping fissure, neither is it crossed by any such fractures or displacements, still less does it owe its origin to an unequal movement of elevation or depression or to rock-flexure. It is as excellent a specimen of an excavated basin as any glacialist could desire.

NOTE C.

Maps showing the Principal Directions of Glaciation in the British Islands, Europe, Asia, and North America. (Plates I., IX., X., XI., XIII., XIV., XV.)

Plate I. is intended to show the general direction of ice-flow over the British Islands during the epoch of maximum glaciation. The red lines indicate the *average* trend of rock-striæ, *roches moutonnées*, and erratics. The directions given for the ice-flow over the sea-floor are of course inferred. It is impossible upon such a small map to represent the minor deflections of the ice-flow caused by the varying configuration of the ground. It must be remembered, however, that such minor deflections affected merely the bottom portions of the *mer de glace*. In some places, as I have shown in the text (see p. 158 and Plate IV.), the 'undertow' of the ice-sheet was deflected to right and left in front of very prominent obstacles, which the upper strata of the *mer de glace* had no difficulty in overflowing. There is another point worth mentioning here, and that is the curious fact that the ice-shed did not always coincide with the water-

parting. Thus, as Messrs. Peach and Horne have shown, the ice-shed in the Northern Highlands lay to the east of the watershed. Similarly we find that in places the ice covering Northumberland was pressed up against the Cheviot Hills and overflowed through some of the passes in that range into Scotland. In like manner ice coming from the basin of the Solway has crossed the Pennine Chain on its way to the east coast. Again, a glance at the map of Ireland will show that the ice-shed in the north lay over the central low-grounds of that region.

The direction of the glaciation in the basin of the Clyde is very striking. The ice which streamed down the vale of the Leven and the Gareloch, instead of flowing out to sea by the Firth of Clyde, was forced away to south-east and east, eventually crossing the whole breadth of Scotland, and doubtless coalescing at last with the Scandinavian ice-sheet. From this we may imagine how great must have been the accumulation of glacier-ice that filled up the lower reaches of the Firth of Clyde, and poured southwards over the bed of the Atlantic towards the south-west coast of Scotland and the north of Ireland. At various places the striæ cross and recross, and there is sometimes an apparent confusion, especially on the high grounds that extend from Renfrewshire into Lanarkshire. These curious appearances are due chiefly to the meeting of the two opposing streams from north and south. These colossal ice-streams met somewhere above Hamilton. Certain appearances would even lead one to infer that the Highland stream sometimes reached as far south as Lesmahagow; for Mr. B. N. Peach got scattered fragments of mica-schist, gneiss, and other typical Highland rocks in the till of that district. But it is evident that the region between Lesmahagow and Cambuslang was a kind of debatable ground upon which the rival ice-streams were liable to occasional deflections. The general trend of the striæ west and south-west of Strathaven, however, clearly indicates that the high grounds in that district were glaciated by the ice that streamed outwards from the Highlands. If we draw an undulating line from the sea-coast near Ayr, north-east to the valley of the Irvine, and thence across the watershed into the Avon, and east to Lesmahagow, then down the valley of the Clyde to Carluke, sweeping it away to the east by Wilsontown, and thereafter continuing it along the crest of the Pentlands and the northern slopes of the Lammermuir Hills, by Reston and Ayton to the sea, we shall roughly indicate the meeting-place of the two great ice-streams. All along this line we have a ‘ debatable ground ’ of variable breadth, throughout which we find a commingling in the till of stones which have come from north and south. South of it characteristic Highland stones do not occur, and north of it stones derived from the south are similarly absent. During the dissolution of the *mer de glace* the direction of flow occasionally became modified—the Highland glaciers, no longer hampered in their course by the ice piled up upon the low grounds, were enabled to follow the natural slope of their beds, and this gave rise to another set of striæ. Examples of such cross-hatching of striæ occur, as my friend, Mr. Jack, has proved, very abundantly in the basin of the Clyde. During the climax of glacial cold the lower reaches of the Firth of Clyde were choked with ice descending from the mountain-glens of Argyleshire, and hence the ice that streamed down the Gareloch and the valley of the Leven was

forced to overflow the high grounds behind Greenock, and so to continue on its way *up* the valley of the Clyde towards Glasgow. Hereabouts the pressure of the ice-sheet advancing from the south began to be felt, and a portion of the Highland ice-stream became deflected, flowing first south-east, then south, and last south-west, while another portion continued on its easterly course across the whole breadth of the country to the North Sea.

Most of the striæ visible in the Lowlands and on the hills of Central Scotland must be assigned to the second epoch of general glaciation. During that epoch, as we have seen, the Scottish ice-sheet was hardly less extensive than its predecessor, and the general directions followed by it probably coincided more or less closely with the trend of the earlier *mer de glace*. Here and there, however, there were local divergences, and possibly some of the 'cross-hatching' of striæ referred to above may be due to such minor changes in the direction followed by the *mers de glace* of those two separate epochs. In some places, however, the direction of glaciation during the earlier epoch of general glaciation differed remarkably from that which obtained during the succeeding epoch, that is, during the formation of the so-called 'upper boulder-clay.' Thus at the time of the earlier and maximum glaciation, the ice, according to Mr. Horne, was deflected eastwards from Criffel along the Triassic plain bordering the Solway, as is proved by the occurrence to the north of Langholm of red boulder-clay, containing blocks of Criffel granite and red sandstone of Triassic or Permian age, as well as fragments of the Birrenswark volcanic rocks. The transport of these erratics shows that the ice-movement must have been slightly to the north of east. But the red boulder-clay in question is overlaid by dark boulder-clay crowded with materials derived from the local valley-systems, with only a few extraneous erratics which have obviously been derived from the older red boulder-clay. The striæ connected with this 'upper boulder-clay' indicate an ice-movement from north to south.

Some of the more remarkable deflections of ice-flow during the maximum glaciation are discussed in the text, but reference may be made here to certain others which have not been specially referred to. Mr. Horne informs me that during the older and maximum glaciation of the Moray Firth region the belt of low ground that forms the southern margin of that Firth, extending eastwards through Northern Banff and Aberdeenshire, was traversed by ice flowing in an easterly direction. At Park, south of Nairn, the striæ point E. 5° N. and E. 17° S. At Forres and Elgin similar evidence is obtained. Near Grange, east of Keith, Mr. Horne detected excellent examples of 'cross-hatchings'—one set of striæ pointing south of east, the other north of east. Boulders of granite from Dirriemore west of Ben Nevis, he tells me, are met with over the Black Isle and on the Morayshire plain, showing that during the maximum glaciation the ice from the Moray Firth invaded the regions referred to—an invasion clearly pointing to the deflection of the Scottish ice-flow owing to the North Sea basin being occupied by a vast *mer de glace*.

Another interesting example of deflection took place in the region of Cantire. Mr. Symes, of the Geological Survey, has proved that the general trend of the ice-markings over the southern part of the peninsula

is a few degrees north of west, while along the transverse hollow at Campbelton it is east and west. On the shore at Campbelton boulders of Arran granite are plentiful; while, at Southend, erratics of quartz-felsite, resembling the quartz-felsite or trachyte of Drum-a-doon, in Arran, are, according to Mr. Peach, of common occurrence. I may mention also that Mr. Wilkinson, of the Geological Survey, has found that the general direction of ice-movement in Islay during the period of maximum glaciation was from south-east to north-west. This is shown not only by the trend of glacial striæ, but by the transport of erratics. Throughout a large part of the island red boulder-clay occurs charged with blocks of red sandstone of Old-Red-Sandstone and Permian (or Triassic) age. Blocks of andesite, identical in character with the andesitic rocks (porphyrites) of the Scottish mainland, are also found in the clay. These rocks do not occur *in situ* in the island, and must have been transported from the mainland.

The principal deflections of the ice in England and Ireland are referred to in the text. Had space permitted, the subject might have been treated in greater detail. For further descriptions of the glaciation of England the reader is referred to Mr. P. F. Kendall's contribution to G. F. Wright's 'Man and the Glacial Period,' chapter vi., and to the late Mr. Carvill Lewis's work, 'The Glacial Geology of Great Britain and Ireland,' which contains many references to original sources of information. The boundary-line for the ice-sheet in Southern England is necessarily more or less conjectural. The lower boulder-clay of our island, like the corresponding ground-moraines on the Continent and in North America, interosculates with and eventually is replaced by 'diluvial' gravel and sand. Hence the precise position attained by the ice-front is more or less uncertain.

I have not attempted to represent upon a map the probable distribution of ice in Europe during what I have termed the first glacial epoch. We have seen that a Great Baltic Glacier existed at that time, and that the marine deposits of the Chillesford and Weybourn Crags were probably contemporaneous therewith. Judging from what we know of the glacial conditions of the Alpine Lands during their earliest recognisable cold epoch, the first Great Baltic Glacier must have attained larger dimensions than that which is represented in Plate XI. But the successive epochs of glaciation that followed could not fail to have obliterated much evidence. If it were not for the presence of the Arctic marine fauna of the Chillesford beds, and the occurrence of the bottom-moraine of the early Baltic Glacier in Southern Sweden, we could not say that the epoch of maximum glaciation in Northern Europe had been preceded in that region by an epoch of less extreme cold conditions. The most complete evidence of this earlier epoch is furnished by the glacial accumulations of the Alpine Lands.

In the maps representing Europe during the second and third glacial epochs (Plates IX., X.), the red lines give what is believed to have been the general direction of ice-flow; while the green patches outside of the region occupied by the 'inland ice' show the mountain-tracts in which glacial phenomena are more or less strongly developed. It will be observed that the ice-shed in Scandinavia did not coincide with the water-parting. The Aralo-Caspian transgression is shown on both maps—although it

cannot be asserted that it was of equal extent throughout the Glacial Period.

Plate XI. represents Europe during the fourth glacial epoch. Here again I have inserted the Aralo-Caspian trangression. It is quite possible that the sea may not have been so extensive at that epoch. Probably it reached its greatest extent during the second glacial epoch when it received the drainage of the vast *mer de glace* which at that time occupied so much of Central and Southern Russia. During the second and third glacial epochs this source of water-supply was cut off, as neither of the lesser ice-sheets crossed the Ural-Baltic watershed. But as both epochs were characterised by excessive precipitation we can hardly doubt that the Aralo-Caspian Sea continued to occupy a wide area. The transgression of the Arctic Sea in Northern Europe and Siberia is represented on Plate XI. The lines are taken from the Geological Map of Russia so far as the region lying east and south-east of the White Sea is concerned. But I have ventured to show the connection which is believed to have obtained at that time between the White Sea and the Gulf of Finland. The evidence for this connection is referred to in the text. Unfortunately all the low-grounds lying between those two regions are obscured underneath younger deposits, and no Arctic shell-beds appear exposed to view.

I may add that on none of these glacial maps has any note been taken of the raised-beaches of the Mediterranean coasts. That changes of level characterised those regions in late Pliocene and in Pleistocene times is well known. But the correlation of such changes with those which took place in the glaciated tracts is at present impossible. In any event the changes of level referred to as having occurred in the Mediterranean area were on such a relatively limited scale that they could hardly have been shown on these small sketch-maps.

The glacial map of Asia (Plate XIII.) is necessarily unsatisfactory. I have merely indicated the areas in which glacial phenomena have been observed. The probabilities are that these were more extensively developed in the mountains and table-lands than the map represents them. I have also ventured to insert several large lakes in the elevated depression of the Han-Hai for the reasons given in the text. Many shallow lakes undoubtedly formerly existed also in the low-grounds of Siberia, especially along the courses of the great rivers. The area covered by the Arctic Sea in North-west Siberia is given from the data furnished by M. Tscherski, and the same author has been followed in drawing the coast-line between the Taimyr Peninsula and Behring Strait. There is not the smallest jot of evidence to show that the Arctic Sea ever communicated with the Aralo-Caspian basin at any stage of the Glacial Period.

Plate XIV. represents North America during the epoch of maximum glaciation, and should be compared with Plate IX., showing our Continent at the same stage. Plate XV. shows the general distribution of the glacial deposits over a wide region in North America, and should be carefully studied along with Professor Chamberlin's descriptions in the text.

NOTE D.

Map of Europe after the Epoch of the last Great Baltic Glacier. (Plate XII.)

This map shows the probable distribution of land and sea in Northern Europe during the stage when the Baltic existed as a great lake (Ancylus Lake), and when the great forests had their widest extension. The surface of this lake would appear to have been about fifty feet or so higher than the present level of the Baltic. The lake ought therefore to have been represented as covering the low coast-lands, but the width of land so covered is relatively so narrow that upon this small map it has been neglected. The courses given for the Rhine, the Elbe, &c., across the bed of the North Sea are, I need hardly say, conjectural. The earlier interglacial epochs would appear to have been similarly characterised by a wide extension of land in North-west Europe—so that this map will also serve in some sort to represent the conditions that obtained during those earlier stages. I have selected the 'Ancylus-Lake' stage for illustration simply because the evidence for it is the most complete. During earlier interglacial epochs it would seem that one or more land-bridges across the Mediterranean united Europe to Africa, but we have no reason to believe that these land-communications existed in later interglacial times.

OF AUTHORS QUOTED OR REFERRED TO.

INDEX.

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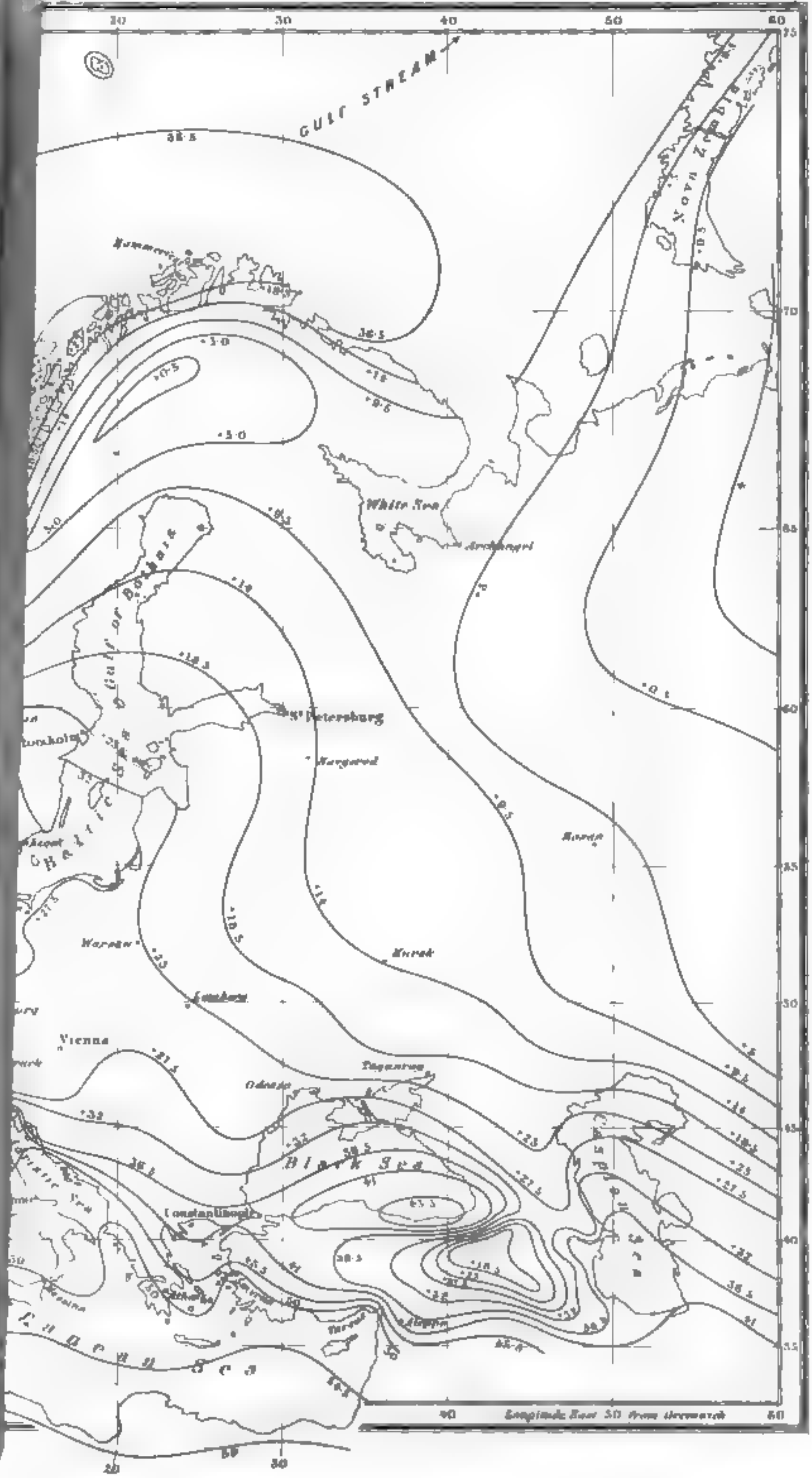
PLATE XVII.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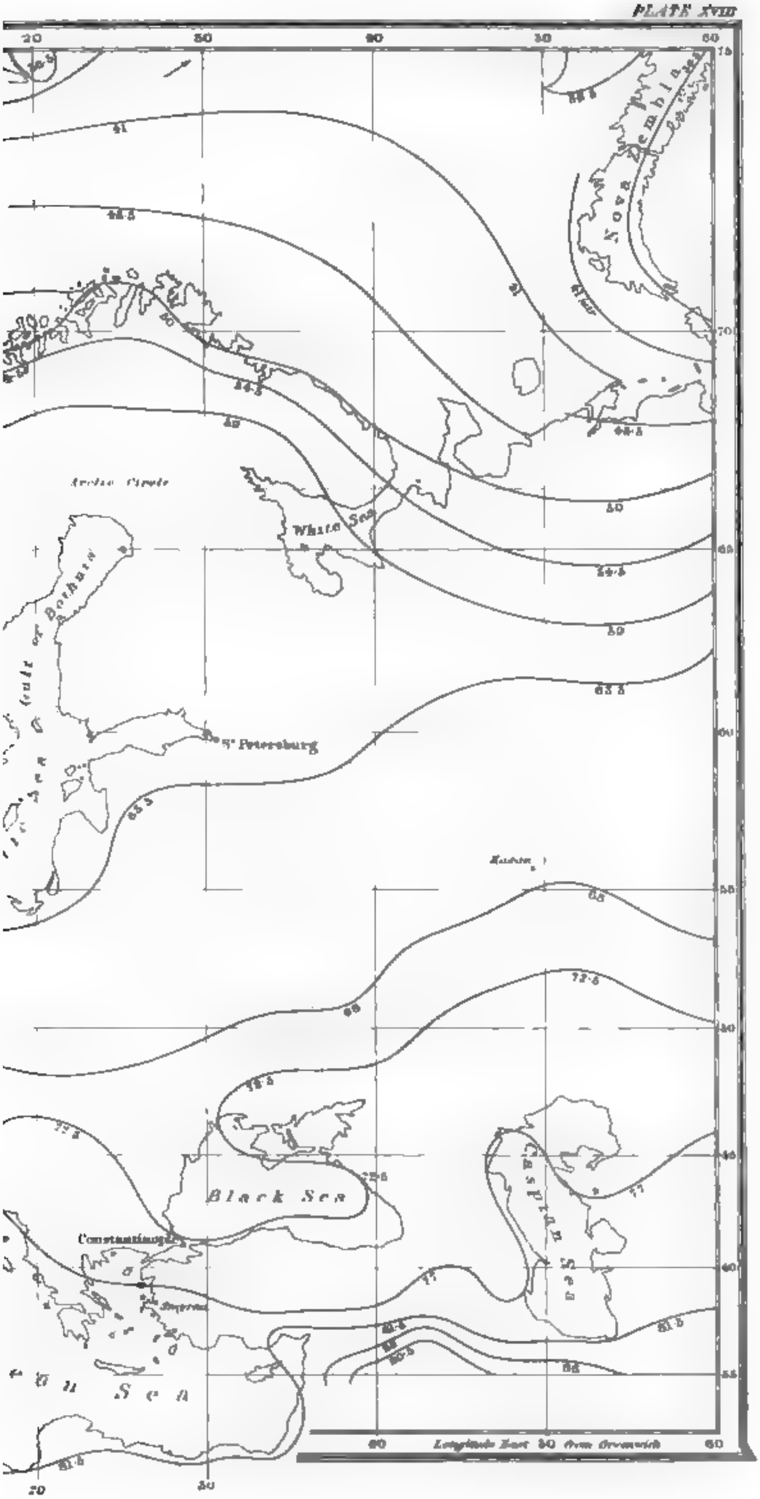
White Sea
Archangel
Gulf of Bothnia
St. Petersburg
Baltic Sea
Novgorod
Kazan
Warsaw
Kursk
Lemberg
Vienna
Odessa
Taganrog
Black Sea
Constantinople
Athens
Aleppo
Nova Zembla
Longitude East 50 from Greenwich


Nova Zembla
White Sea
Arctic Circle
Gulf of Bothnia
St Petersburg
Black Sea
Caspian Sea
Constantinople
Smyrna
Longitude East 50 from Greenwich

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